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LATE PALEOCENE IN THE OTWAY BASIN: BIOSTRATIGRAPHY AND AGE OF KEY MICROFAUNAS

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A planktonic foraminiferal fauna from below the Rivernook Member of the Dilwyn Formation in Victoria is important in earliest Tertiary correlations and age determinations in the Otway Basin. This fauna and the Rivernook fauna previously described are no younger than the *Truncorotaloides aequa* zone and its equivalents in tropical and Mediterranean sequences, and no older than the *Truncorotaloides velascoensis* zone. A review of recent studies indicates that both assemblages are older than Cuisian and that an Upper Paleocene (Ilerdian) age is still justified. There is some doubt about the ancestry of *Pseudohastigerina*, and the important *Pseudohastigerina* Datum seems to lie within the Upper Paleocene rather than at the Paleocene/Eocene boundary.

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INTRODUCTION

There are relatively few horizons in the earliest Tertiary of the Otway Basin to which an age can be given. Two of the marine ingressions in a paralic sequence were dated as Paleocene but only one, the Rivernook Member of the Dilwyn Formation, has a reasonably common and diverse planktonic foraminiferal fauna (McGowran, 1965, 1968b, 1969).

Recognition of "Middle Paleocene" and "Upper Paleocene" right across the Otway Basin (mostly in the sub-surface) depends heavily on these age determinations (Taylor, 1970a, b). Palynological biostratigraphy (Harris, 1965, 1970, pers. comm.) extends correlations far beyond the known occurrences of planktonic or benthonic foraminifera, into Tasmania to the south, Queensland to the north, and the Lake Eyre region to the northwest. The next horizon in the succession to which an age has been given is regarded as early Middle Eocene (Ludbrook and Lindsay, 1969; McGowran, Harris and Lindsay, 1970).

So long as planktonic foraminiferal assemblages are found only in sporadic ingressions (Taylor, 1967) they cannot be assumed to represent the total open ocean fauna of the region at the time, nor can species ranges (as shown by Ludbrook, 1967, fig. 2) be known meaningfully in the region. The open ocean fauna furthermore was marginal to the tropics where species diversities were highest and potential biostratigraphic refinement greatest.

For all of these reasons new data on planktonic foraminifera have a pervading significance for local stratigraphy. This paper discusses an assemblage from just below the Rivernook Member of the Dilwyn Formation at Princetown, Victoria. It is necessary at the same time to discuss recent studies on late Paleocene chronostratigraphy so as to determine what can be meant by the terms "Upper Paleocene" and "Lower Eocene" and what is meant here.

WANGERRIP GROUP

In the Pebble Point to Princetown section in western Victoria (Baker, 1953, Singleton, 1967) the Pebble Point Formation is overlain by the Dilwyn Formation (fig. 1). All samples studied palynologically by Harris (1965) included organic-walled microplankton, so that the environment was at least "marginal marine" throughout. Episodic ingressions (Taylor, 1967) are manifested by horizons

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SECTION (1)		LOCAL BIOSTRATIGRAPHY (2)	
DILWYN FORMATION Dark carbonaceous and pyritic sandy clays. Approx. 600 feet exposed.	PRINCETOWN MEMBER	Q	<i>Planorotalites cf. pseudomenardii</i>
	'Trochocyathus Bed'	R	<i>Planorotalites chapmani</i> s.s.
	RIVERNOOK MEMBER	S	<i>Truncorotaloides aequa</i> (3,4)
	'RIVERNOOK A'	T	<i>Truncorotaloides aff. acuta</i> (4)
PEBBLE POINT FORMATION Ferruginous grits, glauconitic sandstones, silts, shales; two units with horizon of shelly fossils at base of upper. Approx. 80 feet.		U	<i>Planorotalites chapmani ehrenbergi</i> (3)
(Lower Cretaceous)			
(1) See Baker 1953, Singleton 1968.			
(2) Taylor zonules, in Singleton 1968 and pers. comm. For palyno-biostratigraphy, see Harris 1970.			
(3) Faunas described by McGowran 1965.			
(4) Planktonic foraminiferal assemblages discussed herein.			

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Fig. 1. Outcropping section at Princetown, Victoria.

with calcareous macrofaunas and microfaunas. The two foraminiferal assemblages monographed (McGowran, 1965) come from the Pebble Point Formation and the Rivernook Member of the Dilwyn Formation. These and other fossiliferous horizons are good evidence for sporadically open-marine conditions, as shown briefly but clearly by Taylor (1967). Copiapite is common and appears to have derived from pyrite; the possible release of sulphuric acid would destroy calcareous tests (Taylor, 1965). However, the "marine horizons" appear to be real and not merely relics from an initially more complete fossil record because they are widespread in the Otway Basin and can be recognised in borehole sections (Taylor, 1970a, b). The concept of periodic regressions in a paralic regime (Taylor, 1967) would seem more accurate than a relatively simple transgressive-regressive cycle (Bock and Glenie, 1965, Glenie et al., 1968). Taylor's biostratigraphic scheme, based on the section in the Latrobe bore at Princetown, was applied to the outcropping section (in Singleton, 1967) and is included here in an updated form (pers. comm. from Mr. Taylor). Zonule Q is acknowledged by Taylor as possibly Lower Eocene in age. There is insufficient evidence at present to date Zonules Q and R; more material is needed particularly of the name fossils.

PRE-RIVERNOOK PLANKTONIC ASSEMBLAGE

Taylor's Zonule T (fig. 1) is based on a bed which he found below the Rivernook Member and designated informally as "Rivernook A". Usually it is concealed by beach sand and remained unknown since the first studies on the section by C. S. Wilkinson a century ago. Taylor found a planktonic assemblage in Rivernook A, not so rich in specimens as the Rivernook (McGowran, 1965) but excellently preserved. The rock is a distinctively green, slightly indurated clay with silt, glauconite and mica.

Prolonged search yielded excellent specimens although their number is low. The following were identified (specimen numbers included); generic nomenclature is partly after McGowran (1968a) in this list and in the following discussion.

Subbotina patagonica (Todd and Kniker) (10); *S. aff. linaperta* (Finlay) (1); *Subbotina* sp. (2); *Planorotalites planoconica* (Subbotina) (5); *Pseudohastigerina wilcoxensis* (Cushman and Ponton) (11); *Truncorotaloides* (*Acarinina*) *esnaensis* (LeRoy) (7); *T. (Acarinina) cf. nitida* (Martin) (5); *Truncorotaloides* sp. (9); *T. (Morozovella) wilcoxensis* (Cushman and Ponton) (16); *T. (Morozovella) aequa* (Cushman and Renz) (3); *T. (Morozovella) aff. acuta* (Toulmin) (3); *Chiloguembelina* spp. (22) including morphotypes *crinita* (Glaessner), *wilcoxensis* (Cushman and Ponton), *midwayensis* (Cushman), *trinitatis* (Cushman and Renz).

Brief taxonomic notes on this assemblage are included at the end of the report; comments are based also on the collections from the Rivernook Member described previously.

Rivernook A contains, in addition to typical Rivernook elements, the important species *Truncorotaloides aff. acuta* and *Pseudohastigerina wilcoxensis*, one only of the latter having been recorded previously (as *Globigerina pseudoiota* Hornibrook) from the Rivernook Member.

No nannofossils were found in a sample kindly prepared by Dr. H. Hekel (Geol. Surv. Queensland).

COMPARISON WITH THE BASHI MEMBER OF THE HATCHETIGBEE FORMATION IN ALABAMA

Currently the Rivernook Member is correlated with the *Truncorotaloides velascoensis* zone of low latitudes (McGowran, 1968b, 1969). Previously attention was drawn to a considerable faunal similarity to the Nanafalia Formation in Alabama (*Planorotalites pseudomenardii* zone). Figure 2 includes all the biostratigraphic units mentioned in the following discussion.

The planktonic assemblages in the U.S. Gulf and Atlantic coastal sections are rich in acarininids, but all of those described by Loeblich and Tappan (1957), Olsson (1960) and Nogan (1964) contain *P. pseudomenardii* and so belong in the zone of this name. None is known to occur in the *Truncorotaloides velascoensis* zone which, indeed, has not been clearly recognised (Berggren, 1965). There is one possible exception in New Jersey (Olsson, 1969). The Bashi Member of the Hatchetigbee Formation in Alabama, separated from the Nanafalia by the Tusahoma (without planktonics) has a rich acarininid fauna. The presence of *Truncorotaloides subbotinae*, *T. wilcoxensis* and *Pseudohastigerina wilcoxensis* has caused Berggren (1965, 1969b) to place the Bashi above the *Truncorotaloides velascoensis* zone and to date it as earliest Lower Eocene.

A sample of Bashi from Ozark, Alabama, has a rich planktonic fauna. It includes *Pseudohastigerina wilcoxensis* (Cushman and Ponton), acarininids matching the morphotypes *Truncorotaloides (Acarinina) pseudotopilensis*,

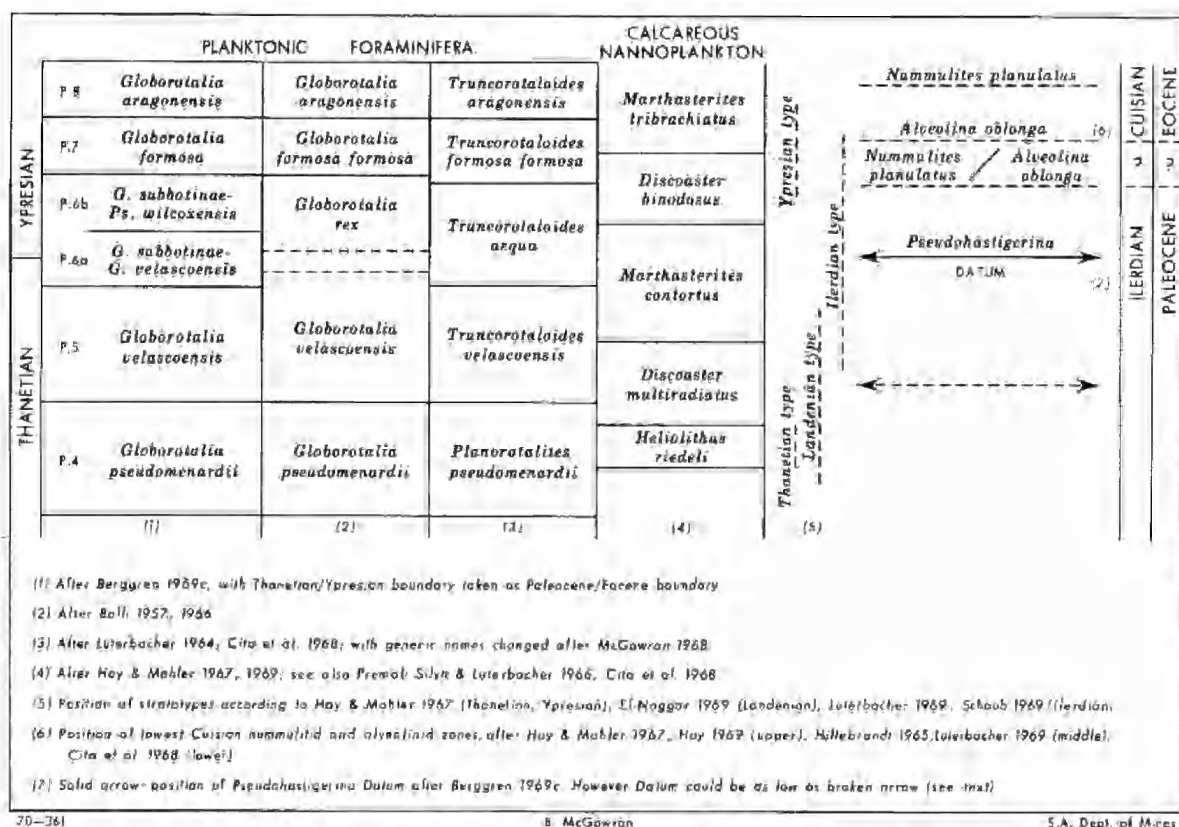


Fig. 2. Biostratigraphy and chronostratigraphy pertinent to correlation and age of Rivernook horizons.

esnaensis, *soldadoensis*, *pentacamerata*, *gruelli* and others, *T. (Morozovella) wilcoxensis* (Cushman and Ponton), *T. aequa* (Cushman and Renz), *T. subbotinae* (Morozova), *T. pusilla laevigata* Bolli, *T. aff. acuta* (Toulmin), *Chiloguembelina wilcoxensis* (Cushman and Ponton), *Ch. milwayensis* (Cushman) s.l.

The only significant absence, with respect to the Rivernook assemblages, is *Chiloguembelina trinitatensis*. The main components not found in Rivernook or Rivernook A are some acariniid morphotypes and the keeled *Truncorotaloides subbotinae-formosa* group.

The Rivernook and Rivernook A assemblages compare more closely with this assemblage than with the assemblage from the Nanafalia illustrated by Loeblich and Tappan (1957).

CORRELATION AND AGE

There are several problems involved in the decision between a Paleocene and a Lower Eocene age for Rivernook A and the Rivernook Member.

(1) Some important species are absent or poorly represented. Comparisons are best with other assemblages outside the tropical belt and the Bashi assemblages now seems closest. Correlations with biostratigraphic sequences in e.g. the Caribbean (Bolli, 1957) or Mediterranean (Luterbacher, 1964; Cita et al. 1968) are made rather difficult. That there is a climatic imprint on these mid-

latitude faunas is indicated by the abundant acarininids (although there is good evidence that regressiveness has a converging effect). The absence of a particular species is less likely to mean that an assemblage lies outside its time range, so that negative evidence can be more misleading than in the tropics.

(2) Unless a correlation can be made directly with a classical stratotype of importance in time-stratigraphic classification (a first-order correlation; Reiss 1966) then the problem of age remains. It is not sufficient to correlate an horizon with e.g. the "*Truncorotaloides velascoensis* zone", no matter how good the correlation may be; palynologists, basin-study compilers and all other workers need the age, e.g. "Upper Paleocene". This link in the chain of correlations back to classical sections involves other fossil groups. Recent studies on calcareous mannofossils are relevant here, as well as in indicating that the Bashi is somewhat older than has been concluded on the planktonic foraminiferal evidence.

As noted above, Berggren has suggested that the Bashi correlates with the "*Globovalia rex*" zone in Trinidad (Bolli, 1957), *T. (M.) subbotinae* (= *rex*) and *T. (?M.) wilcoxensis* being common to both and neither occurring in the *Truncorotaloides velascoensis* zone. Known "species" ranges show a pattern of extinction and radiation in keeled globorotaliids with the *velascoensis-acuta-occlusa* (*simulatlilis*) group being replaced by the newly radiating *subbotinae-marginodentata-formosa* group (Berggren, 1968). But there is a distinct overlap in the *Truncorotaloides velascoensis* and *T. aequa* zones (Luterbacher, 1964, 1966; Cita et al., 1968). Berggren (1969 a, b) has noted that the last members of the *velascoensis-acuta* group overlap with the first *subbotinae*. The association of *T. aff. acuta* with *T. subbotinae-marginodentata* in the Bashi suggests that this assemblage is no younger than this interval of overlap.

Since *T. aff. acuta* occurs in Rivernook A the same criteria apply. The apparent absence of *T. aff. acuta* from the Rivernook Member could mean that it is slightly but significantly younger (by biostratigraphic analysis; obviously it is younger by superposition), but in a mid-latitude, paralic sequence this reasoning is dangerous.

It is less clear that the Bashi and Rivernook A are no older than the "*Globovalia rex*" zone. *T. pusilla laevigata* in the Bashi compares excellently with topotypes, and this species is regarded as distinctively Paleocene (e.g. Berggren, 1968, fig. 1), *T. wilcoxensis* is regarded generally as a post-*Truncorotaloides velascoensis* zone species (e.g. Berggren, 1968) but the *aequa-wilcoxensis* assemblage in the northern Caucasus (Almarina, 1963) correlates in part with the *Truncorotaloides velascoensis* zone (Luterbacher, 1964). *T. subbotinae* and *T. formosa gracilis* are recorded herein from the Bashi, but their distinctness from *T. marginodentata* and *T. aff. formosa gracilis* (Luterbacher, 1964, 1966) is too tenuous to allow confident discrimination between the *T. velascoensis* and *T. aequa* zones.

The acarininid elements typical of Lower Eocene faunas and found in the Bashi have much in common with similar assemblages in the *Planorotalites pseudomenardii* zone, as noted above, and the complex was well established in the *Truncorotaloides velascoensis* zone (e.g. Berggren, 1969c). *Acarinina* and *Truncorotaloides* s.s. seem to have persisted in higher latitudes beyond the level of extinction in the tropics (Berggren, 1969b). There is evidence for this preference for cooler waters in the Middle-Upper Paleocene range of this group. Acarininids are richer and more diverse in the U.S. Gulf and Atlantic coastal region than in Trinidad. As a broad generalisation the Lower Eocene is relatively more regressive than the Upper Paleocene or the Middle Eocene throughout the world. This may have a climatic basis with acarininids becoming more characteristic of low-altitude sequences by invasion at about the time tropical elements

(particularly the *T. velascoensis* group) were declining. A "marginal" assemblage could have a Lower Eocene aspect yet be slightly older, and phyletic lineages in *Acarinina* are not known well enough to exclude this possibility. Assemblages to which it applies include the Bashi and Rivernook, and also the *Globorotalia subbotinae* zone in New Jersey (Olsson, 1969).

It is concluded on foraminiferal evidence that the Rivernook A fauna is no younger than the Bashi, and that the Bashi is no younger than the *Truncorotaloides aequa* zone (*sensu* Luterbacher; see fig. 2) but could well be of the same age as the *T. velascoensis* zone.

Thus the foraminiferal evidence need not contradict nannofossil evidence for correlating the Bashi with the *T. velascoensis* zone. Branlette and Sullivan (1961) regarded the Bashi nannoflora as transitional between their *Discoaster multiradiatus* and *D. tribrachiatus* zones with greater similarity to the former (Upper Paleocene). Hay (1964) placed the Bashi tentatively near the top of the *Marthasterites contortus* zone (which is shown to fill a gap between the Branlette and Sullivan zones; Hay et al., 1967, fig. 2) and slightly above the "*Globorotalia rex*" zone in Trinidad. More recently (Hay and Mohler, 1967; Hay et al., 1967) the Bashi is placed in the *Discoaster multiradiatus* zone, which includes also the *Truncorotaloides velascoensis* zone in Trinidad and northern Italy (but see Cita et al., 1968), and this zone and the *Planorotalites pseudomenardii* zone in the Velasco Shale in Mexico. Indeed, on the correlation of zones presented by Hay and Mohler (1969) the Bashi would fall low in the *T. velascoensis* zone. The "*Globorotalia rex*" zone in Trinidad was said to have a nannofossil assemblage characteristic of the upper part of the *Marthasterites contortus* zone.

The Paleocene/Eocene boundary was placed at the top of the *Truncorotaloides velascoensis* zone (Bolli, 1957, 1966). Berggren (1969 a-c) has moved it slightly higher because of the important overlap noted above, to within subzone P6a (*subbotinae-velascoensis*) (fig. 2). This is regarded as being also the Thanetian/Ypresian Stage boundary, but the evidence for correlating stratotypes of these or other stages (Sparnacian, Landenian) with planktonic foraminiferal zones is very weak, and the evidence from nannofloras shows a gap. Sequences in north-west Europe pertinent to chronostratigraphic classification have, at best, restricted cooler-water and/or regressional assemblages dominated by acarininids and poor or lacking in significant keeled globorotaliids (Berggren, 1960, 1969b; Brönnimann et al., 1968; Moorkens, 1968; El-Naggar, 1969). None of the species identified and discussed by Moorkens from the Ypresian demonstrate that this stage is younger than the Thanetian (as it clearly is); several, indeed, occur as low as the *Planorotalites pseudomenardii* zone. The nannofloras indicate that the type Thanetian lies in the *Heliolithus riedeli* zone and that the type Ypresian is as low as the *Discoaster binodosus* zone (Hay and Mohler, 1967; Bignot and Lezard, 1969).

In the Paris Basin, the nummulitid and alveolinid faunas of the Cuisian Stage can be correlated with faunas in the Mediterranean region and integrated with evidence from planktonic microfossils. The Paleocene/Eocene boundary has been drawn at the base of the Cuisian Stage, at the base of the parallel zones of *Alveolina oblonga* and *Nummulites planulatus* (Hottinger and Schaub, 1960; Hottinger, Lehmann and Schaub, 1964). The Herdian stage of Hottinger and Schaub then is the highest chronostratigraphic unit in the Paleocene. With respect to the biostratigraphic systems based on planktonic microfossils, this boundary has been placed at three closely spaced but rather distinct levels (fig. 2). The *Nummulites planulatus* zone has been identified in the Schlierenflysch in Switzerland within the *Marthasterites tribrachiatus* zone (Hay and Mohler, 1967, and refs. therein) and within its middle part (Hay, 1969). The latter zone is relatively

large (Hay and Mohler, 1969) and the base of the Cuisian could be as high as the *Truncorotaloides aragonensis* zone. However, Bignot and Le Calvez (1969) have recorded *T. subbotinae-marginodentata* from the Cuisian (see also Brönnimann et al. 1968) indicating that the Cuisian should include at least part of the *Truncorotaloides formosa* zone; this is consistent with the range of the Neridian according to Hillebrandt (1965) and Luterbacher (1969). Finally, Schaub (in Cita et al. 1968) has identified the basal Cuisian at an horizon within the *Discoaster binodosus* zone, at about the top of the *Truncorotaloides aequa* zone.

Clearly, there are still problems in relating biostratigraphic systems to a consistent chronostratigraphic framework. In chronostratigraphic enquiry there must be, ultimately, a balance between historical weight and practical value (i.e. circumglobal recognition) and a formal decision as to the best position for the boundary between two stages. It would seem at present that, of the alternatives for a Paleocene/Eocene boundary, the Neridian/Cuisian boundary is the most useful and promising for biostratigraphic correlation, the Neridian fulfilling stratigraphic requirements (Schaub, 1968, 1969; Luterbacher, 1969). The *Truncorotaloides aequa* zone is in the Neridian. This means that the Bashi Marl in Alabama and the Rivernook and Rivernook A assemblages in Victoria are Upper Paleocene in age.

THE PSEUDOHASTIGERINA DATUM

The current trend in Tertiary biostratigraphy is somewhat away from the use of zones, defined in the various ways listed in codes and texts. The differences between mid-latitudes and the tropics, and between nearshore and deep-sea assemblages, account for much of the confusion among existing biostratigraphic systems and the typological, agnostic ("objective") approach to morphotype recognition and definition accounts for some more. Greater attention is being paid to "datum lines" (or "surfaces") particularly as marked by the emergence of a species from a known ancestor in a well-documented phyletic series (either successional shift in observable morphological range or bifurcation, speciation). Total-range zones are the best if the index species has a short range in time ("life") but the lower boundary is the better in any case because it represents a unique event in evolution, whereas the upper boundary is based on extinction which is a "plane" only until demonstrated otherwise. (In practice, some extinctions such as the mass extinction of planktonic species at the top of the Maastrichtian have excellent correlational value.)

One such datum is represented by the first appearance of *Pseudohastigerina wilcoxensis* at or close to the Paleocene/Eocene boundary. It was considered to coincide with the extinction of *Truncorotaloides velascoensis* (Berggren, 1964), and still marks the base of the Eocene even though the ranges of certain other species are changed slightly (Berggren, 1969c) (fig. 2). The value of the datum lies further in the occurrence of *Pseudohastigerina* at latitudes and in facies where important species are not found, and also in that the immediate ancestry has been inferred (Berggren et al., 1967). In the following discussion doubt is cast on the ancestry and on the time of the first appearance.

According to Berggren et al. (1967) *Planorotalites chapmani* (Parr) is the immediate ancestor of *Pseudohastigerina wilcoxensis*. The latter species includes distinctly trochospiral as well as pseudoplanispiral forms (notes on species, below). Occasional specimens with slightly more compressed chambers than usual (Berggren et al., 1967, text-fig. 2d-f) are the only published, visual evidence of ancestry in *P. chapmani*, although Berggren (1964-1969c) has recorded the range of *P. chapmani* as overlapping slightly with *P. wilcoxensis* with some intergradation (e.g. in the Bashi).

This raises the question of the identity and morphological range of *Planorotalites chapmani*. In the original material (McGowran, 1964) this species has a compressed test with rather acute periphery, giving arrowhead-shaped chambers in profile, and it has an imperforate marginal band (McGowran, 1968a, pl. 4, fig. 15, 16). *Globorotalia troelseni* Loeblich and Tappan is a junior synonym and this compressed form appears not to range above the *Planorotalites pseudomenardii* zone (Berggren, 1964). "*G. elongata* Glaessner" auctt. is also synonymous with *P. chapmani*, at least in part (McGowran, 1964). Recently figured specimens of *P. chapmani* from the *Planorotalites pseudomenardii* zone (Berggren et al., 1967, pl. 1) agree with typical *P. chapmani* except that a fully perforate margin is shown (drawing only, not photograph or thin section) and the specimens are small. There seem to be no convincing records published to support the contention that *P. chapmani* ranges well above the *P. pseudomenardii* zone. In Western Australia *P. chapmani* is replaced in the *P. simplex* zone (correlated with the *Truncorotaloides velascoensis* zone; McGowran, 1968b) by a closely related but distinct species identified as *Planorotalites simplex* Haque (McGowran, 1968a, pl. 4, fig. 19-20, 22). *P. simplex* occurs at the same level in West Pakistan (Haque, 1956; see McGowran, 1968b), and in Austria ("*G. elongata*" of Hillebrandt, 1962). Hillebrandt (1965) records *P. simplex* from the *Planorotalites pseudomenardii* and *Truncorotaloides velascoensis* zones in Spain. Although Hay (1960) records "*Globorotalia elongata* Glaessner" from the *Truncorotaloides velascoensis* zone in Mexico, Berggren et al. note the similarity of a figured specimen (Loeblich and Tappan, 1956, pl. 63, fig. 2) to *Globanomalina simplex*; it is not a typical *P. chapmani*. Typical *P. simplex* appear to range down to within *Planorotalites pseudomenardii* zone but, particularly on the Western Australian evidence, *P. simplex* appears to be distinct from and mostly successional to *P. chapmani* rather than a "morphological variant" of the latter as suggested by Berggren et al. Very small specimens in the Bashi are not convincing evidence of a *P. chapmani*-*P. wilcoxensis* phyletic transition, which remains inferential. Specimens identified as *Globorotalia imitata* Subbotina (see especially Loeblich and Tappan, 1957; McGowran, 1965) show very close similarity to *Pseudohastigerina* of the more trochospiral, asymmetrical type, and suggest this species as a likely ancestor. A similarity in wall thickness increases this similarity, in contrast to *P. chapmani* (McGowran, 1968a, pl. 4). However, in the early Middle Eocene of South Australia assemblages of *P. wilcoxensis* include individuals, seemingly intergrading with the typical form, which would fit quite easily in a Paleocene population of *P. imitata*. Cordey et al. (1970), however, maintain the alternative view that *P. chapmani* is the ancestor of *Pseudohastigerina*.

P. wilcoxensis is well known in the *Truncorotaloides aequa* zone and its equivalents (Berggren et al., 1967; Berggren, 1969a-c; Beckmann et al., 1969; Hillebrandt, 1965). A few poor specimens have been found in a sample from the "*Globorotalia rex*" zone in Trinidad. Reasons given above for making the Eridian/Cuiztlan boundary the Paleocene/Eocene boundary mean that these occurrences are of Paleocene rather than Eocene age. Nanofossil evidence for correlating the Bashi with the *Truncorotaloides velascoensis* zone indicates a still lower first occurrence. There is other evidence for this. *Globanomalina ovalis* Haque s.s. is a poorly known taxon (see especially Berggren et al., 1967) but must be very close to *Pseudohastigerina*, yet it is associated near the base of its range (Salt Range, Pakistan) with *Planorotalites pseudomenardii* (see McGowran, 1968b for discussion on Haque, 1956). Latif (1964) records "*Hastigerina pseudoiota* (Hornibrook)" from probable Upper Paleocene, also in Pakistan (McGowran, 1968b). "*Globorotalia* (*Turborotalia*) cf. *pseudoiota*" was found associated with

Planorotalites pseudomenardii in the equatorial Atlantic (Cifelli et al., 1968). Charrier and Lahsen (1968, 1969) recorded a planktonic assemblage from the lower Agua Fresca Formation, southern Chile, with *Globanomalina pseudobiota*, *G. compressa* (Plummer) and "*G. membranacea* (Ehrenberg)" (see notes on species, below). This assemblage has a Paleocene aspect. No *Subbotina patagonica* were reported whereas this species is characteristic of the Agua Fresca (Herm, 1966) and associated with *Pseudohastigerina wilcoxensis*, indicating a Lower Eocene age for the upper part (Berggren, 1969b). Thus, negative evidence also indicates a Paleocene age for Charrier and Lahsen's assemblage. On the other hand, the associated nannofossils have an early Eocene aspect, and the presence of *Discoaster tribrachiatus* suggests an age of no older than *D. binodosus* zone. The first occurrence of *Pseudohastigerina wilcoxensis* in New Zealand is one of Jenkins' main datum planes (Jenkins, 1966) but its actual position is difficult to evaluate from published ranges (Jenkins, 1965). The *Globanomalina wilcoxensis* zone was correlated with the *Truncorotaloides* "rex"-*T. formosa* interval in Trinidad. However, the range of the *T. velascoensis* group appears to be more restricted in New Zealand than Jenkins allows because *P. pseudomenardii* extends above it; thus there is no evidence for a *Truncorotaloides velascoensis* zone. Either important species are restricted or missing for climatic reasons, or part of the section is missing. That is, the problems appear to be the same as in Victoria.

In conclusion, it can be said that there is still room for legitimate doubt about the immediate ancestry of *Pseudohastigerina*, although there is no doubt that it arose from the early Tertiary genus *Planorotalites*. Further studies on its phylogeny and classification are needed. It seems, however, to have emerged during the Upper Paleocene and below the top of the *Truncorotaloides velascoensis* zone.

NOTES ON SPECIES AND MORPHOTYPES

Subbotina patagonica (Todd and Kniker): agrees well with original description and recently identified Lower Eocene forms (Berggren, 1969b) except that the aperture can be even higher.

Subbotina aff. *linaperta* (Finlay): Most Rivernook specimens are not so compressed laterally as specimens of *S. linaperta* from the Bortonian of New Zealand and the refigured holotype from the same level (Hornibrook, 1958a); this comment applies to most pre-Middle Eocene records of *S. linaperta*. *S. trivialis* (Subbotina) may be added to the list of morphotypes given previously.

Planorotalites planoconica (Subbotina): probably a better name for most of Rivernook *P. chapmani* (Parr). Close to but distinct from Pebble Point *P. chapmani* compared with *ehrenbergi* (Bolli) or *haunshergensis* (Cohrbandt). The latter is closer to, but seemingly distinct sample-wise from, *P. australiformis* (Jenkins) from the Middle Eocene of South Australia. It is also probably identical with "*Globorotalia membranacea* (Ehrenberg)" of Charrier and Lahsen (1968). Since *P. australiformis* is recorded from the Upper Paleocene to early Middle Eocene in New Zealand (Jenkins, 1965) the significance of the Pebble Point species as a Middle Paleocene indicator is reduced. Whereas *Planorotalites chapmani ehrenbergi/haunshergensis* occupies a fairly clearcut position in tropical sections (Middle Paleocene; ancestor of *P. pseudomenardii*), and in New Jersey (Olsson, 1969), a lineage extends to the Middle Eocene in mid-latitudes and needs detailed study.

Pseudohastigerina wilcoxensis (Cushman and Ponton): agrees with *Globigerina pseudobiota* Hornibrook (1958 a, b). Aperture and coiling show strong asymmetry (see also Hornibrook, l.c.; Latiff, 1964; Charrier and Lahsen, 1968, etc.)

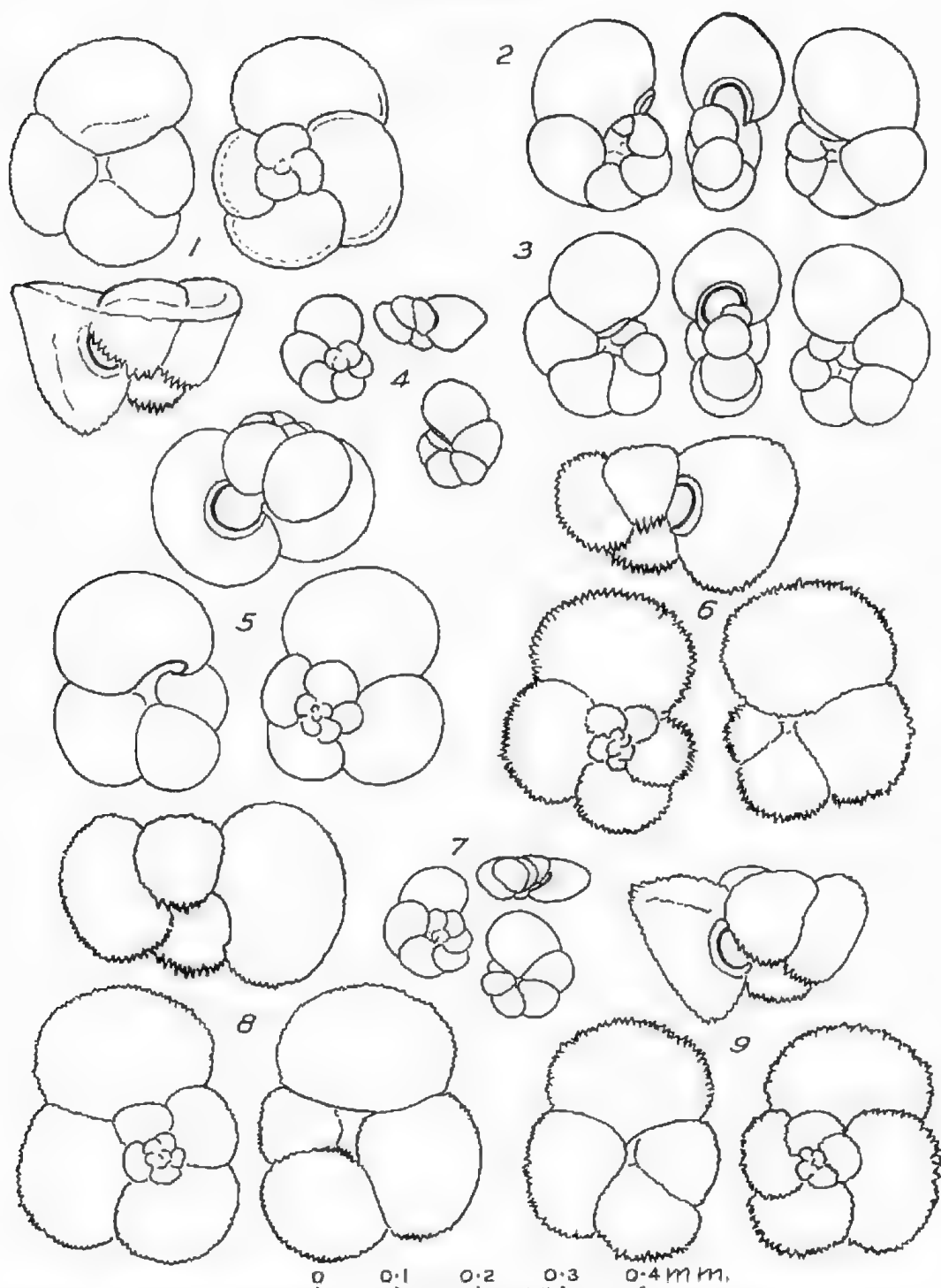


Fig. 3. Planktonic foraminifera from the Rivernook A horizon. Each specimen shown in three views; 1, *Truncorotaloides (Morozovella) aff. acuta* (Toulmin). 2, 3, *Pseudohastigerina wilcoxensis* (Cushman & Ponton) of the asymmetrical, pseudoiota type. 4, 7, *Planorotalites planoconica* (Subbotina). 5, *Subbotina patagonica* (Todd & Kniker). 6, *Truncorotaloides (M.) wilcoxensis* (Cushman & Ponton). 8, *Truncorotaloides (Acarinina) esnaensis* (Leroy). 9, *Truncorotaloides (M.) aequa* (Cushman & Renz).

and there are none of the almost planispiral variants of *P. wilcoxensis* figured from New Zealand and New Jersey assemblages (Berggren et al., 1967) and observed together with the others in topotype material (Bashi Member of Hatchetigbee, Alabama). This primitive aspect persists into the early Middle Eocene in South Australia.

Berggren et al. suggested that *G. pseudoiota* should be placed in synonymy with *P. wilcoxensis*, but further study (Cordey et al., 1970) indicated that it may be better placed in *P. sharkriverensis* Berggren and Olsson. The early members of the lineage are rather problematical, especially in Australia as acknowledged by Cordey et al., and the name *P. wilcoxensis* is tentatively maintained here pending further clarification. Incidentally, these authors' discussion of my (1968a, fig. 1) "view on the phylogeny of the pseudohastigerinids" goes well beyond the original intention; the "view" was merely to use sufficient morphotypes to indicate an evolutionary trend for the purposes of genus-group and family-group classification.

Truncorotaloides (Acartinina): acarininids are notoriously variable and intergradational in the Upper Paleocene and Lower Eocene (see, however, useful discussion of synonymy by Berggren, 1968). *T. (A.) esnaensis* and *T. (A.) cf. nitida* in Rivernook A may be distinct, but much larger assemblages in Rivernook proper range from *pentacamerata* Subbotina or *soldadoensis* Brönnimann through a "central" group of *esnaensis*, *intermedia* Subbotina, etc., to *triplex* Subbotina, *pseudotopilensis* Subbotina, etc. Tightly coiled pre-Middle Eocene forms referred by several authors to *primitiva* Finlay can mostly be distinguished from this species.

Truncorotaloides sp.: small, five-chambered, rounded (cf. *pentacamerata* Subbotina) or truncate and flattened spirally (cf. *apanthesma* Loeblich and Tappan). Occurs in Rivernook and also Bashi.

Truncorotaloides (M.) *aequa* and *T. (M.) wilcoxensis*: lumped previously, but specimens in Rivernook proper compare very well with topotypes of both forms. Same in Rivernook A.

T. (M.) aff. acuta: strongly truncate, highly conical chambers, angular and slightly keeled margin, umbilical shoulders with slight thickening. Compares well with topotypes of *T. acuta* but lacks strong thickening of shoulders seen in largest and in those closest to *velascoensis* (Cushman) (see e.g. Loeblich and Tappan, 1957). Not found in Rivernook proper but occurs in Bashi. Very similar to specimens in *Planorotalites pseudomenardii* zone in south India which in turn provide link with *T. conicotruncata* (Subbotina).

Chiloguembelina spp.: morphotypes listed appear to be matched in Rivernook A and Rivernook proper (see Beckman, 1957), but consistent separation into coherent taxa is rather doubtful even with excellent material.

CONCLUSIONS

(1) The Rivernook A assemblage is similar to the Rivernook assemblage except that there are fewer specimens. *Truncorotaloides* aff. *acuta* is present and *Pseudohastigerina wilcoxensis* is relatively well represented.

(2) Both assemblages are characteristic of acarininid-rich, mid-latitude faunas in the early Tertiary, and the similarity with the Bashi Member of the Hatchetigbee Formation in Alabama is particularly striking.

(3) Recent studies of calcareous nannofossils indicate that the Bashi correlates with the planktonic foraminiferal zone of *Truncorotaloides velascoensis* rather than slightly higher. It is concluded on foraminiferal evidence also that the Bashi and Rivernook assemblages need be no younger, but that a range in

possible correlation including the *Truncorotaloides velascoensis* zone and (?lower) *Truncorotaloides aequa* zone is the most precise presently justified.

(4) The Ilerdian/Cuisian boundary seems to be the best position for the Paleocene/Eocene boundary. Both of the assemblages from the Dilwyn Formation are Ilerdian and therefore Upper Paleocene in age.

(5) The evolution of *Pseudohastigerina wilcoxensis* from *Planorotalites chapmani* has not been demonstrated completely and remains inferential. *Planorotalites imitata* is a possible alternative ancestor. The *Pseudohastigerina* Datum lies within the Upper Paleocene, not at the Paleocene/Eocene boundary. It could be close to the base of the Ilerdian.

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AGE DETERMINATION OF POUCH YOUNG AND JUVENILE KANGAROO ISLAND WALLABIES.

BY CLARE R. MURPHY AND JANCE R. SMITH**

Summary

Repeated measurement of head, leg and foot lengths were made during the development of young Kangaroo Island wallabies (*Protemnodon eugenii*) of known age. The measurements were used to construct age regressions. Size was fairly closely correlated with age until the young were 320 days old but thereafter it had little value for age determination. The reliability of using the regressions to determine the age of young wallabies has been tested by using them to estimate the age of 14 young of known age. The largest error between the estimated and actual age of the young was about 5%. Growth proportions of captive and field-reared young were compared and these were found to be similar until the young were about 350 days old.

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Growth proportions of captive and field-reared young were compared and these were found to be similar until the young were about 350 days old.

INTRODUCTION

Several studies made on the growth rate of marsupial young in the pouch have shown that the age of young captured in the field can be accurately estimated by comparing their body measurements with those of captive young of known age (Shield and Woolley, 1961; Sadleir, 1963; Sharman, Frith and Calaby, 1964). A study on the ecology of the Kangaroo Island wallaby (*Protemnodon eugenii* Desmarest) living in Flinders Chase, Kangaroo Island, required a method for accurately determining the age of pouch young and juvenile wallabies captured in the field (Andrewartha and Barker, 1969). For this reason the growth of captive pouch young was studied and the reliability of using these measurements to determine the age of captive pouch young was assessed. The present study also examines the validity of applying these measurements to fixing the age of young Kangaroo Island wallabies in the field.

METHODS

During this study a domestic colony of Kangaroo Island wallabies was maintained in the Zoology Department, University of Adelaide. Details of animal husbandry are reported by Murphy (1970).

During the breeding season (January-July), the pouch of each female was examined daily until the birth of a young; the young were subsequently measured each week until they were about one year old. Yearlings were measured once a fortnight because of their slow growth rate. A total of 16 young were observed throughout the study but at any one time only seven young were measured.

The lengths of the head, left foot and left leg were measured in the manner indicated by Sharman et al. (1964). Vernier callipers were used to measure head and foot lengths of all the animals and the leg length of pouch young, while a steel tape measure was used to measure leg lengths of older animals. Fourteen of the young were weighed at intervals throughout the study; most of them were weighed several times. They were weighted on a variety of balances since no one balance covered the range of their weights.

Until they were 100 days old, the young were removed from the pouch and measured while still attached to the teat. Older pouch young were detached from the teat and measured. During measurement of the young, the mothers were restrained in jute sacks; no young were lost through the handling of the mothers.

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Juveniles and yearlings were restrained in jute sacks while their body parts were being measured.

Both operators measured the young every time and the average of the two estimates was taken to the nearest 0.1 mm. with the callipers and to the nearest 0.5 mm. with the tape measure. Weights were recorded to the nearest 0.1 g.

Before regressions calculated for young wallabies reared in the laboratory can be used to age young in the field, it is necessary to establish that wallabies in the laboratory and the field have the same growth proportions. For this purpose 87 young wallabies were collected at different times of the year in Flinders Chase, Kangaroo Island and were measured and weighed by one of us (C.M.) in the same way as the laboratory-reared animals.

RESULTS

The measurements made on laboratory-reared young aged 3-450 days are presented as regressions of age versus head length, leg length and foot length (Figures 1, 2 and 3).

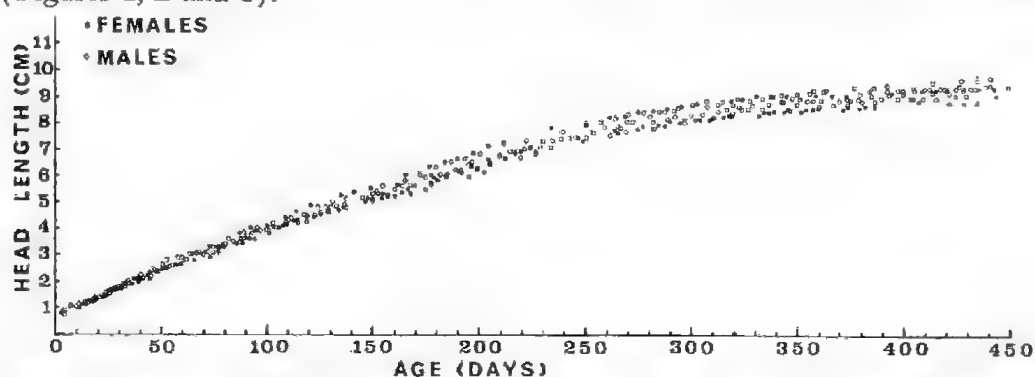


Fig. 1. Regression of head length on age for Kangaroo Island wallabies aged 3-450 days.

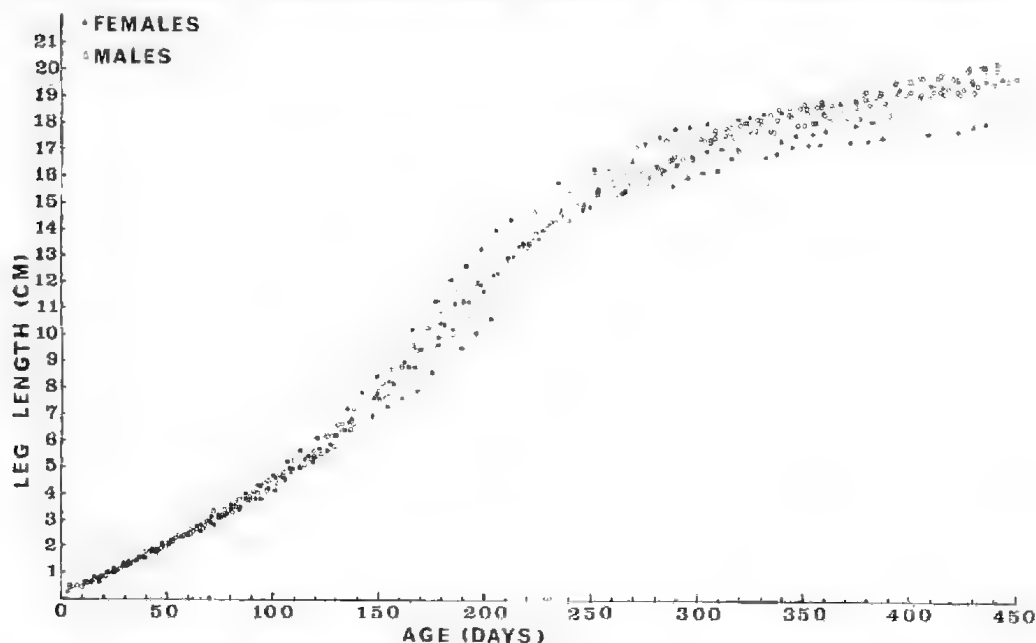


Fig. 2. Regression of leg length on age for Kangaroo Island wallabies aged 3-450 days.

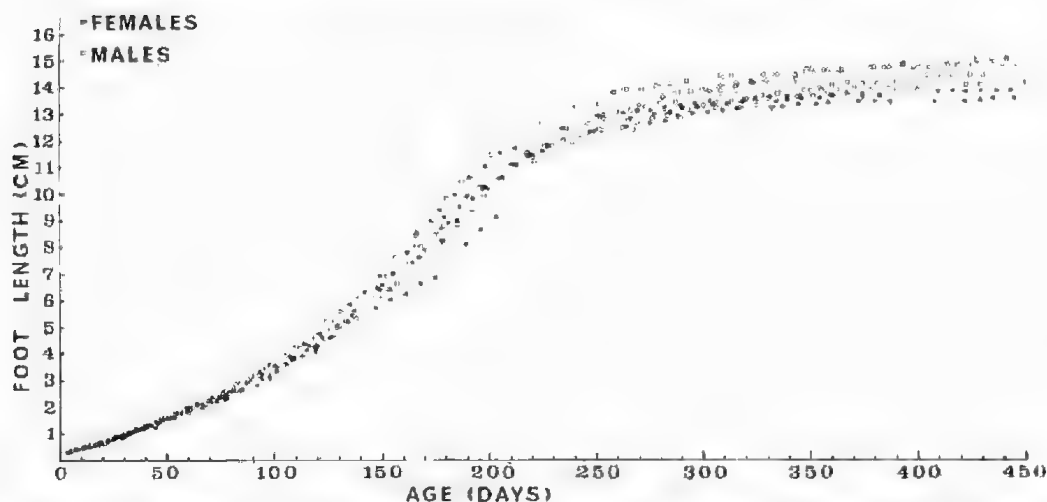


Fig. 3. Regression of foot length on age for Kangaroo Island wallabies aged 3-450 days.

The regressions show no marked differences in the growth rate of young male and female wallabies up until the time they leave the pouch permanently at 245-270 days. From this time the regressions for male and female young begin to diverge, the males being on average larger than the females.

Inspection of the three regressions shows a considerable scatter of points, much of which is due to the difficulty of making accurate measurements on the young. An age estimation based on a single body measurement could therefore be subject to a greater error than an estimation based on all three body measurements.

A series of measurements were also made on 14 young of known age which were not included in the regressions. Table 1 shows the measurements of these young, together with their ages as estimated from the three regressions, and their actual ages.

TABLE 1
Measurements of young Kangaroo Island wallabies of known age, not included in the growth regressions, and the ages of these young estimated from the regressions.

Reference Number and Sex	Lengths (cm.)*			Estimated Age (Days)†	Actual Days (Days)
	Head	Leg	Foot		
74(?)	0.87 (4)	0.41 (5)	0.33 (5)	5	8
1 ♂	1.12 (12)	0.61 (12)	0.41 (8)	11	10
2 ♀	1.22 (15)	0.69 (14)	0.55 (14)	14	16
3 ♂ (?)	1.29 (17)	0.78 (17)	—	17	17
14 ♂	1.67 (27)	1.15 (26)	0.84 (27)	27	26
67 ♀	2.00 (36)	1.42 (34)	1.08 (35)	35	36
595 ♂	2.78 (58)	2.45 (57)	1.84 (59)	58	59
14P ♂	3.77 (92)	4.03 (91)	3.18 (95)	93	94
84 ♀	4.35 (115)	5.31 (116)	4.15 (114)	115	111
77 ♀	4.42 (118)	5.50 (120)	4.34 (118)	119	123
594 ♀	4.50 (121)	5.83 (124)	4.90 (126)	124	129
76 ♀	5.45 (162)	8.74 (164)	7.55 (166)	164	163
94 ♀	5.79 (174)	9.76 (176)	8.47 (177)	176	185
SE ♂	6.45 (199)	11.80 (197)	10.74 (203)	200	197

* Estimated ages from each measurement are in parentheses.

† Based on average of ages estimated from each measurement.

It can be seen that the largest actual error in age estimations for any of the young was nine days when the estimate was made from all measurements (young no. 94 ♀, Table 1). This represents an error of about 5%.

Figures 1, 2 and 3 show that size is fairly closely correlated with age until the young are 320 days old, but thereafter it has little value for age determination.

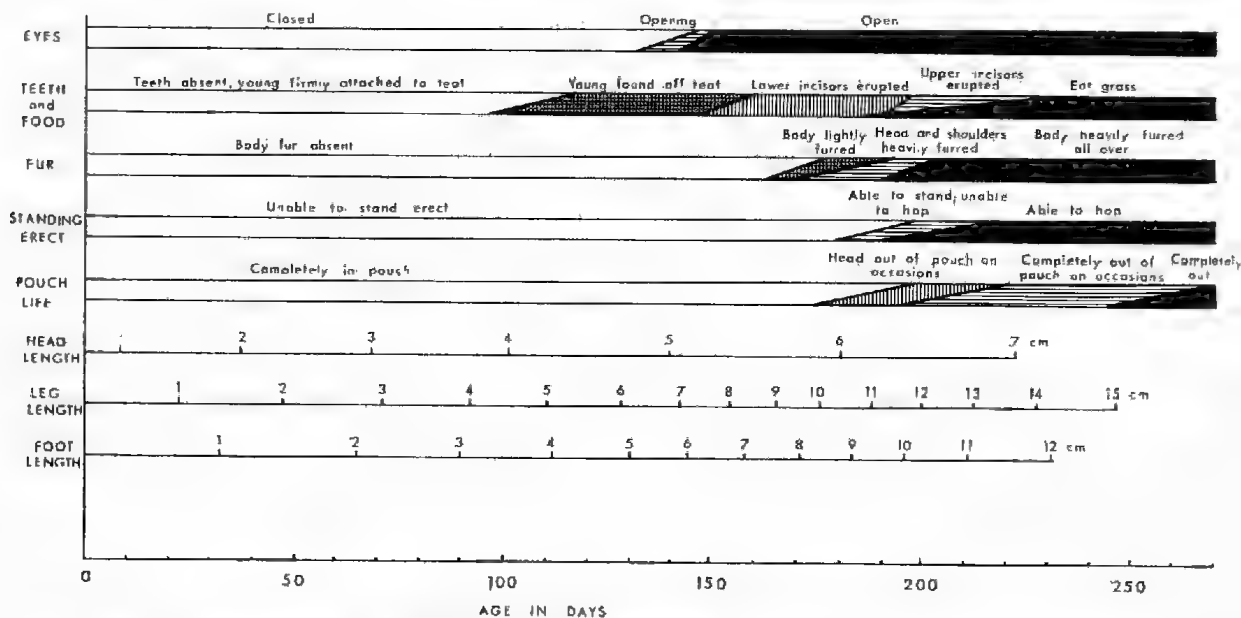


Fig. 4. Development of body characters and changes in body proportions of Kangaroo Island wallabies aged 0-270 days. The legend is as stated on the figure. The sloped lines indicate the range of ages over which the character develops.

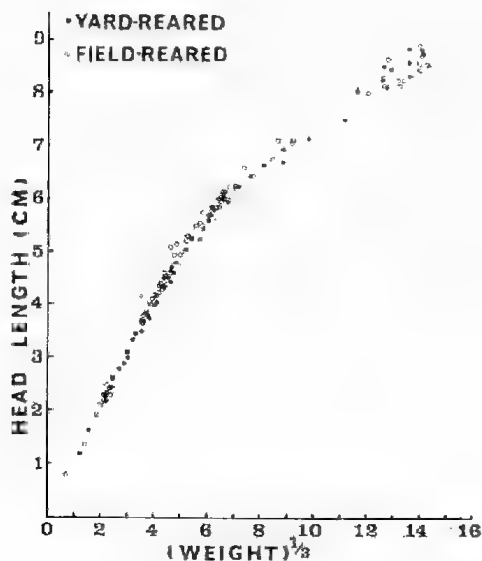


Fig. 5. Regression of head length on cube root of body weight of young Kangaroo Island wallabies reared in captivity or in the field.

During the study some observations were made on the development of various body features of the young, and changes in their body proportions as they grew older were also recorded. These observations are presented diagrammatically in Figure 4.

Figures 2 and 4 show that the leg has the longest period of rapid growth and it appears that in using leg length as a criterion for age, if males and females are considered separately, an error of between 20 and 45 days might occur when aging young 320 days old.

Figures 5-7 present the regressions of cube root of weight (condition) against the lengths of head, leg and foot (age) for laboratory- and field-reared wallabies.

These regressions show no marked differences in the growth proportions of laboratory- and field-reared young up to an age of about 350 days.

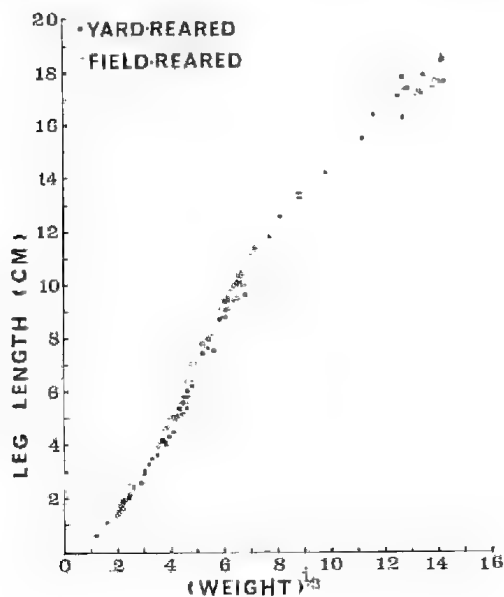


Fig. 6. Regression of leg length on cube root of body weight of young Kangaroo Island wallabies reared in captivity or in the field.

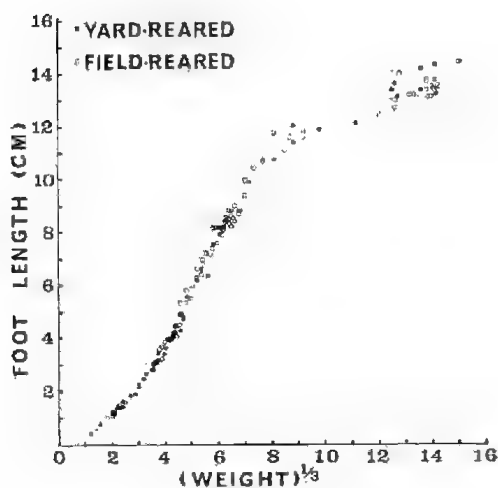


Fig. 7. Regression of foot length on cube root of body weight of young Kangaroo Island wallabies reared in captivity or in the field.

DISCUSSION

The growth rate of young macropods in the field is extremely difficult to estimate. Shield and Woolley (1961) found that growth proportions of compound- and field-reared quokkas did not differ significantly, and so considered that the growth rates of field and captive animals were probably similar.

A comparison of growth proportions between pouch young of curos from the field and from laboratory yards was carried out by Sadleir (1963). He found that there was generally little difference between the condition of young from the field and from the yards and concluded that nutrition in the field was never poor enough to restrict the growth of the pouch young. Sharman *et al.* (1964) drew a similar conclusion for pouch young of the red kangaroo. They suggested that the comparatively stable environment of the pouch led to an "all or none" growth phenomenon and that the body measurements of the young provide a reasonably accurate indication of their age.

The present study shows that the growth proportions of laboratory- and field-reared Kangaroo Island wallabies do not differ significantly in young aged less than 350 days. This is despite the observation that adult female wallabies in the field may be short of nitrogen and water at certain times of the year (Murphy, 1970), while laboratory-reared females were never short of food and water. It seems that the level of nutrition of female wallabies in the field is generally adequate so that growth of the pouch young is not restricted. It is possible that maternal malnutrition may severely affect the growth of the young, but it seems that this rarely occurs in the field.

This study thus shows that size, as estimated from body measurements, provides a reliable indication of the age of laboratory- and field-reared Kangaroo Island wallabies until they are 320 days old.

ACKNOWLEDGMENTS

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A REVISION OF AUSTRALIAN GENERA OF ARCHAEOCYATHA

*BY F. DEBRENE**

Summary

The paper gives a brief reconsideration of the systematics of Archaeocyatha and tables of their classification. For the Class Irregularia, a first attempt is made to distinguish genera by standard diagnostic characters. An alphabetic catalogue gives revised diagnoses of genera occurring in Australia and their placing in families, together with other relevant information. Three new species which are type species of new genera are described in an appendix.

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INTRODUCTION

The aim of this paper is mainly to give the specialists on Archaeocyatha the new definition of every genus established on Australian material, either by the first authors T. G. Taylor, R. W. R. and J. Bedford, or by subsequent designation. In fact, original collections being acquired by different Museums, it is very difficult to have this work done; I am indebted to Professor M. F. Glaessner from the University of Adelaide, Dr. B. Daily, formerly at the South Australian Museum, Professor A. G. Fischer and Professor B. F. Howell from Princeton University, Dr. W. Ball from the British Museum (Natural History) who agreed to loan to me from the collections in their keeping, or for the last three, who gave me the opportunity of studying in their Department.

Besides the types of genera and species, there are very numerous undescribed fossils; recently Dr. B. Daily and Dr. M. R. Walter kindly sent me further new material. A complete revision will take me at least one more year. The results of these studies will be published as a monograph by the "Muséum d'Histoire Naturelle", Paris, not before 1972 or 1973.

This is the reason why, on the advice of Professor Lehman, Director of the Institute of Paleontology of Natural History Museum (Paris) and Professor Glaessner, University of Adelaide, I decided to write a catalogue of the Australian genera.

This paper gives for each genus: its type-species, and the place where it is kept.

—the original diagnosis by the author of the genus, or when there is no diagnosis for the genus, as it often occurs in Bedford's papers, the diagnosis of the type specimen, with the omission of indications which are relevant only on the specific level.

—the present diagnosis after restudying typical material.

—when necessary a discussion concerning the differences between original and present diagnosis or its affinities.

—the place of the genus in present classification.

Because of some considerations for the present edition, it was not possible to give an iconography of genera, Taylor's, Hill's and Debrenne's photographs filling this gap for the present. Only new genera are figured here; I hope that complete illustrations will appear in my next monograph.

Studies on outgrowths are not included; it would require a special work including Siberian and American specimens to state, as far as possible, their

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significance. *Somphocyathus*, *Ardrossocyathus*, *Exocyathus* and *Metaldetymorpha* are consequently not listed in this paper.

Before the enumeration in alphabetic order of the Australian genera, I shall recall some principles of systematics and give tables in which each genus can be easily placed.

CONSIDERATION OF THE SYSTEMATICS OF ARCHAEOCYATHA

Till now, Archaeocyatha are subdivided into two main groups, Regulares and Irregulares (Class Regularia Vologdin 1937 and class Irregularia Vologdin 1937) according to their first stages of development, taking the apex of *Dokidocyathus* as the type of the Regulares, and the apex of *Rhizocyathus*, *Alphacyathus* or *Dictocyathus* (according to different authors) as the type for the Irregulares.

Regular Archaeocyatha can be placed into a satisfactory classification established on simple rules (Zhuravleva 1960, Debrenne 1964). The changes in their classification come from new data, such as the discovery of new types of wall, or the recognition of homologies in outer wall development (Rozanov 1966-1969). They mainly concern supra-family levels. The classification of Irregulares is not so clear, for several reasons. First of all, special studies on this group are not so numerous. Second, as they are of "irregular" appearance it is always difficult to establish the real spatial connections between the different elements of the intervallum structures. This requires more than 2 or 3 oriented sections per sample. The result is that they are often described as "vesicular or taenioid intervallum structures", "alveolar" or "scattered rods". Important genera as *Archaeocyathus* Billings, *Archaeosycon* Taylor (based on broken specimens which cannot be cut to show how they are built up) or *Dictyocyathus* (the type-specimen of which is lost and I was unable to find unquestionable topotypes in Sardinia, the Bornemann's description and figuration being too poor) are not well known. This lack in our knowledge stands in the way of establishing rules of classification for Irregulares.

Thirdly, these forms are probably more primitive than Regulares: they do not build highly specialized skeletal layers as complicated as the walls of Regulares, the main characteristic features of the adult are reached later during growth, and often concealed by persistence of secondary exothecal or endothecal lamellae, bulges, buds or encrusting forms in which the intervallum frame is more or less disturbed. Development of vesicular tissue is not constant but frequent. Synapticalae (or tangential links) occur in many cases; the more delicate the vertical frame and the more frequent the tangential links, the greater the irregular appearance of different sections.

The individual development is of little help for classification in such plastic forms, except for the distinction between Regulares and Irregulares. The individualization of the inner wall, the specialization of the outer wall and the radial arrangement of intervallum structures, the disappearance of secondary structures in the central cavity do not occur at the same level of growth amongst specimens from the same genus, or even from the same species.

Therefore, the primitive elements of apical parts (rods or booklets) represent potentially many kinds of adult structures in Irregulares, and here they are most probably initially dependent on the environment more than in the strongly built Regulares; thus they could not be used to define "recapitulated stages of evolution" and to state phylogenetic rules for systematics, as some previous authors have suggested.

My studies on Australian Irregulares and on some Moroccan and Sardinian ones, generally of oldest stratigraphical age, lead me to believe that there is

a strong tendency to build radial vertical structures which, finally produce adult forms very similar to *Regulares*. I have proposed to call these structures "pseudosepta" and to distinguish several types (Debrenne 1969a p. 332). These pseudosepta are not always in true vertical planes like the septa of *Regulares*. As I have stated before, when the skeletal material is thin, the connections are often distorted. On the other hand the pseudosepta are affected by wavy disposition at the level of synapticalae, the opposing crests corresponding to synapticalae.

When the skeleton becomes more important, these features disappear and the genus looks regular. Tabulae are present, either as sieves linked to a peculiar horizontal development of synapticalae, or as independent structures.

To distinguish in practice true Regular forms from Irregular ones with radial structures, when the apex is unknown (the great majority of the specimens are broken above the apex), the structure of the outer wall is the main feature. The porosity of pseudosepta is always important, even though this character is not yet well studied in *Regulares*. In *Irregulares* the pores have often various diameters; the pores occur along lines slanted obliquely upwards and outwards (with a more or less acute angle) from the inner wall, and then gently curved near the outer wall. Tabulae and inner wall have peculiar arrangements, but they have also some structures in common with *Regulares*: synapticalae and vesicular tissue, generally more frequent in *Irregulares*, are known in *Regulares*; so their presence is not sufficient to determine the class.

The problem of *Syringocnema*, which has radial honeycomb tubes is not clear. In some respects they resemble some "tube like-structures" built by the wavy sides of septa and flat synapticalae of *Pycnoidocyathus* type. In other ways, by the constant diameter of pores and the regular honeycomb construction, this genus resembles regular *Archaeocyatha*. The holotype of the type species being poorly preserved, we need some more detailed studies to settle this question. This genus is temporarily placed as *incertae sedis*.

The classification of *Regulares* is based on the following scheme:

—primitive structures of internal space extending into the apex give the definition of **ORDERS**.

—elaboration of the different types of intervallum structures give the definition of the **SUBORDERS**.

—differentiation of the outer wall (which is reached before that of the inner wall) gives the definition of **SUPERFAMILIES**.

—at least differentiation of the inner wall gives the definition of the **FAMILIES**.

—the **GENERA** are established on subcategories of the porosity of walls (section of canals, of annuli, disposition of and correlation between pores, increase of the porous surface by vertical corrugations, etc.), and of porosity of intervallum structures.

As a working hypothesis, I suggest for *Irregulares* a table of classification based on the same pattern as above (Table A). As far as I know, this suggestion is not in opposition to their own growth pattern; but we must not forget that the differentiation of internal structure is established later than in *Regulares* and could be disturbed secondarily during growth by exothecal lamellae, budding bulges and so on. The main argument in favour of this viewpoint is that outer wall (a superfamily character) is the most characteristic feature separating *Irregulares* with regular intervallum structures from *Regulares*. It is difficult to define the main types of intervallum and walls until the whole class is exhaustively restudied; I for myself have not enough stratigraphical data (specially from upper part of the Lower Cambrian) to establish the limits of subdivisions with

certainty. Anyway, these new propositions are made to give rise to further discussion. This is the first attempt to unify the criteria of classification as between Regulares and Irregulares. Future studies will improve this method, if acceptable, or find another satisfactory scheme for the whole phylum.

TABLES OF CLASSIFICATION

Class REGULARIA

Order—MONOCYATHIDA—one wall.

Suborder MONOCYATHINA—internal space empty.

Family—simply porous wall— Monocyathidae

Monocyathus

Family—simple tumuli— Tumuliolynthidae

Tumuliolynthus (*M. irregularis* BEDFORD)

Order—AJACICYATHIDA—intervallum with radial partitions—

Suborder DOKIDOCYATHINA—intervallum with radial rods—

Superfamily DOKIDOCYATHACEA—outer wall simple—

Family—inner wall simple— Dokidocyathidae

Dokidocyathus

Acanthinocyathus

Suborder PUTAPACYATHINA—intervallum with only tabulae—

Superfamily APTOCYATHACEA—outer wall simple—

Family—inner wall simple— Aptocyathidae

Alphacyathus

Superfamily PUTAPACYATHACEA—outer wall with alternating pillars—

Family—inner wall with alternating pillars Putapacyathidae

Putapacyathus

Suborder AJACICYATHINA—intervallum with radial septa—

Superfamily AJACICYATHACEA—outer wall simple—

Family—inner wall simple, several pores per intersept— Ajacicyathidae

Ajacicyathus

Family—inner wall simple, one pore per intersept—Robustocyathidae

Robustocyathus

Stapicyathus

Family—inner wall simple several pores + protection structures— Tennericyathidae

Cadniacyathus

Family—inner wall with ethmophylloid canals (sensu lato)— ?Ethmophyllidae

Zonacyathus

Family—inner wall with one canal + annular plates— Ethmocyathidae

Ethmocyathus

Family—inner wall with annular shelves— Cyclocyathellidae

Thalamocyathus

Family—inner wall with annular shelves and canals — Bronchocyathidae

Cyathocricus

Superfamily ANNULOCYATHACEA—outer wall with simple tumuli—

Family—inner wall with one pore Tumulocyathidae

Dailycyathus (*Paranacyathus margarita*)

- Superfamily SIGMOCYATHACEA—outer wall annulate—
 Family—inner wall annulate— *Sigmocyathus* Sigmocyathidae
- Suborder NOCHOROICYATHINA—intervallum with radial septa and pectinate tabulae—
 Superfamily NOCHOROICYATHACEA (outer wall simple)—
 Family—inner wall with one canal + annular plates— *Ethmopectinus* (lineatus pars) Ethmopectinidae
 Family—inner wall with annular shelves and canals— *Glaessnericyathus* (sigmoides) Glaessnericyathidae
 Suborder COSCINOCYATHINA—intervallum with radial septa and tabulae—
 Superfamily ERISMASCOSINACEA—outer wall simple—
 Family—inner wall simple— *Erismascosinus* (australis, bilateralis, textilis etc.) Erismascosinidae
 Family—inner wall annulate— *Rozanovicosinus* (fonini)—asperatus pars) Stillicidocyathidae
 Superfamily SIGMOCOSINACEA—outer wall with protection structures—
 Family—inner wall annulate— Sigmocoscinae
 Superfamily CALYPTOCOSINACEA—outer wall: frame + microporous sheath—
 Family—inner wall simple + spines— Polycoscinae
 Superfamily ALATAUCYATHACEA—outer wall: tumuli—
 Family—inner wall simple + spines— Tumulocoscinae
 Superfamily ANAPTYCTOCYATHACEA—outer wall frame + sieves—
 Family—inner wall simple— Anaptyctocyathidae

Class IRREGULARIA

Based only on Australian, West European, and North African material. Must be completed by studies of material from higher stratigraphic levels.

Types of internal structures:

- one wall; central cavity filled
- two walls

Types of intervallum structures:

- I—Cylindrical rods radial and oblique: CHOURBERTICYATHIDA
- II—Rods and booklets vertical and oblique: ARCHAEOPIARETRIDA
- III—Pseudo-septa (plates with wide pores to true radial plates with small, numerous pores the area of which is less than that of the skeleton), without or with synapticalae, or with synapticalae and pseudo-tabulae (synapticalae in horizontal planes + sieves) METALDETIDA
- IV—Stout radial septa without synapticalae and tabulae: PARANACYATHIDA
- V—Septa and independent tabulae: PARACOSCINIDA

OUTER WALL		INNER WALL												IV		V	
scalloping of radial bores and tangential ribs		scalloping of radial bores and tangential ribs															Pyrodictospongia
frame + 3 eyes		frame + 3 eyes															
frame + microporous sheath		frame + microporous sheath															
diagonal tube per interscapulum		diagonal tube per interscapulum															Stromatopora
oblique tube for interscapulum		oblique tube for interscapulum															Stromatopora
one pore per "interscapulum"		one pore per "interscapulum"															Stromatopora
irregular pores		irregular pores															Stromatopora
scalloping of radial bores and tangential ribs		scalloping of radial bores and tangential ribs															Stromatopora
frame + 3 eyes		frame + 3 eyes															Stromatopora
frame + microporous sheath		frame + microporous sheath															Stromatopora
3 spines tube per interscapulum		3 spines tube per interscapulum															Stromatopora
1 oblique tube per interscapulum		1 oblique tube per interscapulum															Stromatopora
one pore per "interscapulum"		one pore per "interscapulum"															Stromatopora
regular pores		regular pores															Stromatopora
scalloping of radial bores and tangential ribs		scalloping of radial bores and tangential ribs															Stromatopora
frame + 3 eyes		frame + 3 eyes															Stromatopora
frame + microporous sheath		frame + microporous sheath															Stromatopora
3 spines tube per interscapulum		3 spines tube per interscapulum															Stromatopora
1 oblique tube per interscapulum		1 oblique tube per interscapulum															Stromatopora
one pore per "interscapulum"		one pore per "interscapulum"															Stromatopora
irregular pores		irregular pores															Stromatopora
cylindrical rods		cylindrical rods															Stromatopora
radial rods		radial rods															Stromatopora
oblique rods		oblique rods															Stromatopora

Classification—Table of Irregular Archaeocyathia of Australia.

Types of outer wall:

- non-porous*
- aperture of intervallum without independent sheath
- irregular pores*
- one pore linked to the septa
- frame + microporous sheath*

* present in Australia

Types of inner wall:

- irregular pores
- one pore
- one canal straight or sigmoid
- frame + microporous sheath
- frame + sieves
- scaffolding of radial plates and flat tangential booklets.

As this is a first attempt at a new way of classification I do not give names to superfamilies until subsequent studies corroborate or invalidate the underlying hypothesis (see Table A).

Acanthinocyathus BEDFORD and BEDFORD 1936

(pro *Acanthocyathus* BEDFORD and BEDFORD, 1934, p. 4, fig. 20)

Type species. *Acanthinocyathus apertus* BEDFORD and BEDFORD (1934, p. 4, fig. 20). Lectotype: British Museum (Natural History) S 4166.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford 1934, p. 4). The specimens agree with normal Archaeocyathinae in the possession of two walls; these are united by a very scanty framework of delicate radial rods. The inner wall is a very open simple polygonal net. The outer wall is built up, as it were, of a series of fused spicular elements enclosing large open spaces; spines or tubercles often project outwards beyond the general wall surface. The spitz, so far as known, has the same open net-like structure.

Present diagnosis (After restudying typical material, Debrenne 1969a, p. 306). Two-walled cups with radial, horizontal or sometimes oblique cylindrical rods. The inner wall consists of a large porous net, with a mesh of irregular size formed by skeletal threads of constant thickness. The outer wall has large pores in quincunx; the skeletal tissue occupies a smaller area than the pores and carries long spines that are directed upwards and outwards.

Discussion. R. and W. R. Bedford thought that the inner wall was a scaffolding of triradiate spicules. This suggestion is not borne out by observation: the outer wall is a porous sheet with the elongation of its horizontal skeletal parts into scales of an unusual size.

Systematic position. Family Dokidocyathidae BEDFORD and BEDFORD 1936.

Ajacyathus BEDFORD and BEDFORD 1939

Type species by original designation: *Archaeocyathus ajax* TAYLOR (1920, p. 118, pl. 1a-e, j, k; pl. 3). Lectotype T. 1550a, University of Adelaide, chosen in an article in the press (Paleontologicheskii Zhurn., Moscow).

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1939, p. 73-74). "... Outer wall delicate with extremely fine pores distributed regularly. ... Septa regularly arranged and

numerous, with pores rather remote and small, . . . Inner wall rather solid with regularly arranged pores, some being 'stirrup-pores', others not. . . " Two-walled cups, solitary or colonial with regular radial septa.

Present diagnosis. Outer wall thin and regularly porous. Inner wall larger and stout, with regular pores; the inner wall and the septa are connected by one vertical row of stirrup-pores. Between two adjacent septa, one or more rows of pores are observed, arranged together with stirrup-pores in a quincunxial pattern. Radial septa straight and stout, with few, or no pores.

Discussion: The lack of porosity of septa is now considered as a generic characteristic; the result of this being the individualisation of each interseptal loculus. The presence of stirrup-pores at the inner wall is an important specialization. When septa are completely non-porous, exchanges between adjacent loculi are possible only at the level of stirrup-pores.

Systematic position. Family: Ajaiecyathidae BEDFORD and BEDFORD 1939.

Alphacyathus BEDFORD and BEDFORD 1939

Type species by original designation: *Dictyoecyathus annularis* R. and W. R. BEDFORD (1936, p. 13, fig. 55). Holotype P 942, South Australian Museum, Adelaide.

Original diagnosis (R. and W. R. Bedford 1936, p. 13, fig. 55). "Small tubular form, . . . Outer wall pores are obscured in the type specimen, but a second specimen . . . shows small irregular pores. . . . The short connecting rods in the intervallum tend to anastomose into horizontal rings. . . . The inner wall has small circular pores. . . ."

Emended diagnosis (R. and J. Bedford 1939, p. 72, fig. 169).

" . . . there is a tendency of these (the rods) to be united by a single tangential row of synapticalae to form incomplete horizontal platforms a kind of forerunner of the tabulae of *Coscinocyathus*. This feature is specific and not essential to the genus. . . ."

Present diagnosis. Small cylindrical cups, with two simply porous walls. In the intervallum regularly spaced horizontal structures are present. They consist of cylindrical rods rising radially from the walls, but interrupted by tangential rods. There are no continuous bars from wall to wall, but tabulae-like structures with more or less quincunxial pores. One inner wall pore at each interradian space and at each horizontal level.

Discussion. The horizontal platforms which were regarded by R. and J. Bedford as only specific structure are now considered as generic characters and detailed examination shows that there are no true radial rods connected by annular synapticalae.

Systematic position. Family Aptocyathidae Konjushkov 1964.

Anaptyctocyathus DEBRENNE 1969

Type species *Coscinocyathus cribripora* R. and W. R. BEDFORD. Holotype: British Museum (Natural History) S. 4160.

Original diagnosis (Debrenne 1969a, p. 340). Cylindrical cup. Intervallum with straight radial septa, in which the hexagonal pores occupy a much larger surface in proportion to the skeletal tissue, and irregular flat tabulae that are finely perforated by very narrow pores. The inner wall is simple, with two rows of pores per interseptum, which are only weakly separated; in fact towards the upper part of the cup two neighbouring pores may coalesce. The pores of the outer wall are covered by knobs that are perforated by a central pore and a surrounding circle of six others.

Present diagnosis. The outer wall consists of a frame, with large pores, each of them being covered by a sieve, instead of low tumuli.

Discussion. A. Yu. Rozanov recently pointed out three types of "double wall". One of these corresponds to the structures of the outer wall of *cribrilporu*. Comparison with material from the Soviet Union makes it certain that there are no true tumuli but double walls with a simple frame covered by non-independent sieves.

Systematic position. Family Anaptyctocyathidae fam. nov.

Archaeofungia TAYLOR 1910

Type species by monotypy: *Archaeofungia ajax* TAYLOR (1910, p. 131, pl. 12, fig. 67, fig. 25). University of Adelaide No. T 1566.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (Taylor 1910, p. 131). "Cylindrical or conical forms without annulations, of small size with a comparatively narrow central cavity. They are characterised by a very strong development of synapticalae and appear to form a transition genus between *Archaeocyathus* and *Pycnoidocyathus*, . . ."

Present diagnosis. Small cylindrical or conical cups with smooth undulations. The apex is surrounded by exothecal lamellae and at the same level till a diameter of 10 mm. is reached, the central cavity is filled up by oblique porous tubes, which arise from the inner wall and become nearly vertical at the central part of the cup. The upper part of the central cavity is free of any skeletal elements; the inner wall has one horizontal canal per interseptum. The outer wall, at first concealed by exothecal lamellae is of double porosity, the first frame with irregular pores is covered by a microporous sheath. Septa radial, with few pores, connected by irregularly spaced synapticalae (Debrenc 1969b).

Discussion. The examination of typical material removes the doubts on this genus. It belongs to the Irregulares. Regular forms with synapticalae have to be put in the genus *Sibirecyathus* VOLODIN, which is not a junior synonym of *Archaeofungia*.

Systematic position. Family Archaeofungiidae fam. nov.

Archaeopharetra BEDFORD and BEDFORD 1936

Type species by monotypy: *Archaeopharetra typica* R. and W. R. BEDFORD 1936 p. 17, fig. 75. Holotype P.969, South Australian Museum.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford 1936, p. 17). "Small irregular tubular organisms, the space within the outer wall filled with a mass of irregular trabecular and dissepimental tissue without central cavity or defined inner wall. . ."

Emended diagnosis (R. and J. Bedford 1937, p. 31). ". . . has centrally, in the upper part a kind of crude, irregular inner wall".

Present diagnosis. After restudying typical material: small cups with a non-porous outer wall horizontally striated by small annular corrugations. A true inner wall is defined for a diameter of 2 mm., but it could be concealed by the presence of skeletal bars and vesicular tissue in the central cavity; the intervallum is filled up by irregular skeletal elements, bar- or plate-like, mainly placed in vertical or oblique position, but more or less radial, vesicular tissue is also present. The apical part often consists of one wall and vesicular tissue only.

Discussion. The main new data is the presence of a true inner wall commencing at a diameter of 2 mm., and some tendency to a radial disposition of the elements.

Systematic position. Family Archaeopharetridae fam. nov.

Bedfordcyathus VOLOCIN 1957

Type species by monotypy: *Metacyathus irregularis* BEDFORD and BEDFORD (1934, p. 6, fig. 29). Holotype: British Museum (Natural History) S4189.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (after R. and W. R. Bedford 1934, p. 6).

Large irregular conc, with wavy outer wall the inner wall following a similar contour; wide cavity. . . . The outer wall has an underlying layer of fairly large irregular pores masked by a finer network. . . . Septa straight and delicate, easy to expose in transverse and tangential section, but not in radial section. No satisfactory trace of inner wall.

Emended diagnosis (after Debrenne 1969a, p. 360). The inner wall appears to be covered by an irregular microporous sheath which screens the simple pores.

Discussion (after Debrenne F. 1969a, p. 355). There is no appreciable difference from *Metacyathus* in the structure of the intervallum (apart from the abundance of vesicular tissue) or in that of the walls. Consequently *Bedfordcyathus* is considered as identical with *Metacyathus* which is a junior synonym of *Metulidetes*.

Beltanacyathus BEDFORD and BEDFORD 1936

Type species by original designation: *Beltanacyathus ionicus* BEDFORD and BEDFORD (1936, p. 23, fig. 96). Holotype no. 86716, Princeton University.

Lower Cambrian, Paint Mine, South Australia.

Original diagnosis (R. and J. Bedford 1936, p. 23). "Large conical cups with remote coarse-pored septa; the outer wall an irregular fine mesh carried by an underlying coarser mesh; the inner wall composed of exceedingly large regularly arranged canals leading upwards and inwards into the central cavity . . . coarse vertical fluting may be present."

Present diagnosis. Large conical cups, sometimes with vertical fluting. Intervallum with two kinds of radial partitions: (1) complete septa, running from outer to inner wall, strong, pierced by regular pores—the area of which is smaller than that formed by skeleton—and (2) vertical radial plates, in the middle of each interseptum, arising from the outer wall, not larger than $\frac{1}{4}$ of the space between the two walls, with no pores except one row against the outer wall. Outer wall double: the main frame consists of tubes of irregular polygonal openings, screened outwardly by a second microporous sheath. Inner wall with one pore tube per intersept, in horizontal and vertical lines. Tubes are long, set at a very acute angle with the wall. As far as known, radial septa are present down to the apex.

Systematic position. Family Beltanacyathidae fam. nov.

Cadniacyathus BEDFORD and BEDFORD 1937

Type species by original designation: *Cadniacyathus asperatus* BEDFORD and BEDFORD (1937, p. 36, fig. 152). Holotype 86616, Princeton University.

Lower Cambrian, Cadnia, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1937, p. 36). "Archaeocyathina with vertical flutes to the outer surface, the furrows corresponding to the positions of the septa; the inner wall with scale-like hooks projecting upwards and inwards into the central cavity. . . ."

Present diagnosis. Conical cups with vertical fluting. The outer wall has round pores regularly settled in quincunx. Septa straight, pierced by small remote pores. The inner wall consists of 2 or 3 rows of pores per intersept lined up horizontally. A horizontal plate arises from the lower edge of each pore, and joins

laterally the neighbouring one, so as to build a crude incomplete annular shelf which protected several pores. Jagged rim into the central cavity.

Discussion. This genus is very close to *Tennericyathus* ROZANOV 1969 which corresponds to the uncorrugated form of *Cadnucyathus*.

Systematic position. Family *Tennericyathidae* ROZANOV 1969.

Coplecyathus BEDFORD and BEDFORD 1937

Type species by original designation: *Coplecyathus confertus* BEDFORD and BEDFORD (1937, p. 29, fig. 116 A-D). Holotype 86741, Princeton University.

Lower Cambrian, Paint Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1937, p. 29). "... A central cavity is present, at least in the upper part. Septa are numerous and are of 'wire-netting' character; although they are in places traceable right across the intervallum, they are very irregular and more often curve and anastomose with neighbouring septa. The inner wall is of very unusual type, being a thick, felted mass of curved anastomosing rods continuous outwardly with septal mesh. ..."

Present diagnosis. Outer wall simple, rather thick, with pores less wide than skeleton. It is supported by some scarce spurs, coming out from septa. Septa are straight, the pores of which are irregular in form and size, grading from round to nearly rectangular. Synapticulae present, rather numerous near the inner wall. The inner wall is of quite complex structure. It looks like a second intervallum, with three times more crowded radial plates, connected by tangential ones. This felted mass opens directly into the central cavity, without any other specialized sheath.

Discussion. The septa are straight and radial and generally do not curve (as Bedford had stated). Their more or less irregular appearance depends on the orientation of sections, according as to whether they cross a skeletal part or pores, or cut tangential links. The intervallum and inner wall structures of the same pattern.

Systematic position. Family *Coplecyathidae* BEDFORD and BEDFORD 1937.

Coscinoptycha BROILI 1915

(pro *Coscinoptycha* TAYLOR 1910)

Type species by subsequent designation of Simon 1939, p. 26: *Coscinoptycha convoluta* TAYLOR (1910, p. 141, pl. XI, fig. 60). Holotype by original designation, University of Adelaide T. 1594.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (Taylor 1910, p. 141, pl. II, fig. 6, pl. VI, fig. 32, pl. XI, fig. 60-63, fig. 6-8).

"The shape is that of an extremely irregular and warped folded sheet, having very little resemblance to a regular cup, but better described as a warped bowl, of flabellate expansion. ... It is of a large size judging from fragment preserved. ... The intervallum is always quite small varying from one to two millimeters. The septa are regularly arranged, straight, and numerous. Tabulae are present at rather remote but regular intervals. The genus is based on the general shape of the organism. The septate lamina has occasionally large re-entrant foldings, so that the outer wall becomes concave. ... The cup like form probably grades into that of the present genus. ..."

Present diagnosis. Bowl-shaped cups with few perforate to imperforate septa and remote microporous tabulae. Vesicular tissue occurs when tersioid growths appear. Inner wall with 2 or 3 rows of pores protected by spines. Outer wall with one row of simple tumuli per intersept, perforated laterally.

Discussion. Material coming from the type locality enables us to state the position of inner (two rows of pores) and outer (one row of pores) walls, that corroborates Taylor's view.

Systematic position. Family Tumulocosciniidae ZHURAVLEVA 1960.

Cricopectinus gen. nov.

Type species: *C. dentulus* sp. nov. pro *Ethmophyllum dentatum* TAYLOR (pro parte) Taylor pl. XIV fig. 89. Holotype T 1589 B.

Diagnosis. Cup with radial septa, unperforated except for one vertical row of pores near the outer wall, and pectinate tabulae. Outer wall simple, with pores contracted outwardly; inner wall complex: horizontal lined canals serve as apertures for several loculi. They extend into central cavity by an annular shelf with deeply cogged free rims.

Systematic position. Glaessnericyathidae fam. nov.

Cyathocricus DEBRENNE 1969

Type species: *Archaeocyathus tracheodentatus* R. and W. R. BEDFORD 1931. Holotype: British Museum (Natural History) S 4754.

Original diagnosis (DEBRENNE 1969a, p. 318). Cup with a simply porous outer wall; straight, sparsely perforated radial septa and an annulate inner wall. Annuli consist of undulating, horizontal or slightly inclined plates, that are neither S- nor V-shaped; their axial rim is cogged.

Systematic position. Family Bronchocyathidae R. and J. BEDFORD 1936.

Dailycyathus gen. nov.

Type species by original designation: *Paranacyathus margarita* (BEDFORD and BEDFORD (pl. 1, figs. 4, 5). Holotype 87214, Princeton University.

Diagnosis. Large conical cups with regular radial septa and inner wall, but central cavity with skeletal structures arising from inner wall, near the apex. Adult stages could reach a large diameter with narrow intervallum, with vesicular tissue still present. Outer wall has one row of pores between 2 adjacent septa; each pore is covered by an hemispherical cap perforated laterally; inner wall has one row of stirrup-pores in front of each septa. Septa radial and imperforate except at the level of stirrup-pores.

Discussion. The presence of secondary skeletal structures in the central cavity is not a sufficient feature to place *Dailycyathus* amongst Irregulares; this kind of filling is known in many specimens of true Regulares. On the contrary, stirrup-pores and tumuli are typical features of Regulares.

Systematic position. Family Tumulocyathidae KRASNOPEEVA 1953.

This genus is dedicated to Dr. B. Daily, formerly South Australian Museum, now University of Adelaide.

Dictyocoscinus BEDFORD and BEDFORD 1936

Type species by monotypy: *Dictyocoscinus beltana* BEDFORD and BEDFORD. Holotype P 946, South Australian Museum.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford 1936, p. 14, fig. 62).

Two walls connected by an open mesh similar to that of *Dictyocyathus*. At intervals a series of horizontal sieve-plates fill the interstices of the mesh, forming a tabular structure resembling that of *Cosciniocyathus*.

Present diagnosis. Small cups only known. Outer wall non-porous. Inner wall with pore-tubes, alveoles, leading upwards and inwards into the central cavity; radial pseudo-septa, regularly made of plates, rather than rods, arranged in radial planes and connected by synapticalae. Some synapticalae are developed in horizontal planes. The holes defined by these synapticalae and the septa are screened by sieves with rather regular pores.

Systematic position. Family Dictyocosecinidae BEDFORD and BEDFORD 1936.

Dokidocyathus TAYLOR 1910

Type species by monotype: *Dokidocyathus simplicissimus* TAYLOR (1910, p. 146, pl. 13, pl. 77A, pl. 16, pl. 91-92). Holotype T 1589 AB, University of Adelaide.

Original diagnosis (after Taylor 1910, p. 146). "... Stout outer wall united to the yet stronger inner wall by remarkably few septa. The latter were particularly thick ... , several longitudinal sections through the middle of the cups ... (show) that intervallum was unoccupied by any connecting skeleton except a few struts which crossed it at remote intervals. ... "

Present diagnosis. Long cones, with outer and inner walls simply porous, the intervallum between vertical rows of pores being strengthened by vertical ridges projecting into the intervallum from inner wall and outwards from outer wall. Radial partitions consist of flat plates settled in vertical plane, as septa with one large pore, the diameter of which is nearly equal to that of the intervallum.

Discussion. The species included in *Dokidocyathus* with cylindrical radial rods rather than flattened plates generally occur at lower stratigraphical levels (Tommotian stage) than *simplicissimus*. After comparison with the Siberian material and discussions with Russian specialists, I interpret the particular structure of the type species as indicating a tendency towards construction of true septa from rods.

Systematic position. Family Dokidocyathidae BEDFORD and BEDFORD 1936.

Erugatochyathus DEBRENNE 1969

Type species: *Coscinochyathus papillatus* R. and W. R. BEDFORD (1934, p. 3, fig. 12). Holotype: British Museum (Natural History) S 4153.

Original diagnosis (Debrenne 1969a, p. 334). Septa with remote round pores. Tabulae reticular. ... The circular pores of the base of the coarsely porous outer wall are covered by a microporous sheath, in which each group of micropores consists of a central pore surrounded by 5 others. A skeletal tongue covers each simple pore of the inner wall.

Discussion. Till now, stellate or non-stellate inner walls are considered as sub-genus characters. *Erugatochyathus* is the unfolded form of *Tomocyathus* ROZANOV 1960, but Rozanov (personal communication) points out that stellate or fluted interseptum spaces correspond to an increase of porous surface and consequently could be of generic value.

Systematic position. Family Polycoscinoidea DEBRENNE 1964.

Ethmocoscinus SIMON 1939

Type species by original designation: *Coscinochyathus papillipora* BEDFORD and BEDFORD (1934, p. 4, fig. 18). Holotype: British Museum (Natural History) S 4164.

Original diagnosis (R. and W. R. Bedford 1934, p. 4).

"... Septa ... with numerous fairly large pores. Tabulae remote ... with numerous small pores. The outer wall has one or two rows of very characteristic

pores per intersept each pore entering a hollow hemispherical papilla projecting outwards from the wall, with an external perforation in the lower part of the papilla. The inner wall is also very characteristic; each intersept has a single row of thick-walled tubular pores leading upwards and inwards into the central cavity. . . ."

Present diagnosis (Debrenne 1969, p. 339). Cylindro-conical cups. Outer wall with simple annuli, one per interseptum. Inner wall with a single row of S-shaped pore tubes per interseptum. Septa have sparse simple pores; tabulae with polygonal, somewhat irregular pores.

Systematic position. Family Tumulocosciniidae Zhuravleva 1960.

Ethmocyathus BEDFORD and BEDFORD 1934

Type species by monotypy: *Ethmocyathus lineatus* BEDFORD and BEDFORD (1934, p. 2, fig. 8).

Lower Cambrian, Ajax Mine, Beltana, South Australia. Holotype: British Museum (Natural History), S 4149.

Original diagnosis (R. and W. R. Bedford, 1934, p. 2, fig. 8).

Ethmocyathus lineatus, the type and only species so far found, differs considerably from such genera as *Cyclocyathus* as it has three or four minute horizontal rings running across each pore of the inner wall.

Present diagnosis (Debrenne 1969a, p. 323). Cup with straight radial, sparsely porous septa. The outer wall has close, simple pores. The inner wall is composed of a thin sheet of hexagonal to rhombic pores, screened from the central cavity by thin, narrow horizontal annuli.

Systematic position. Family Ethmocyathidae DEBRENNE 1969.

Ethmopectinus gen. nov.

Type species: *E. walteri* sp. nov. pr *Ethmocyathus lineatus* BEDFORD and BEDFORD (pro parte). Holotype 86762, Princeton University.

Diagnosis. Conical cups with radial perforated septa and pectinate tabulae; outer wall gently fluted slit pores in quincunx, of small area outside as compared with skeletal pores, larger inside. Inner wall double: rhomb pore tubes, one per intersept screened by annular horizontal plates in the central cavity.

Systematic position. Family Ethmopectinidae fam. nov.

Flindersicoscinus gen. nov.

Type species by original designation, *Flindersicyathus tabulatus* BEDFORD and BEDFORD (1937, p. 29, fig. 111). Holotype 86666, Princeton University (pl. 11, fig. 3).

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1937, p. 29).

"... closely resembling *E. decipiens*. . . . The special feature . . . is the presence of upwardly convex 'growth tabulae'; these occur at irregular intervals. . . ."

Present diagnosis. Outer wall irregular. Inner wall with one pore per intersept. Pseudo-septa are connected by synapticalae—the pores between skeletal elements are large compared to skeleton. Pseudo-tabulae are synapticalae arranged in horizontal plane with secondary subdivisions and thickening, but no sieves.

Systematic position. Family? Pyenoidocyathidae OKULITCH 1950.

Flindersicyathus BEDFORD and BEDFORD 1937

Type species by subsequent designation of Bedford and Bedford 1939, p. 78: *Flindersicyathus decipiens* BEDFORD and BEDFORD (1937, p. 28, fig. 109 a-b). Holotype 86670, Princeton University.

Original diagnosis (R. and J. Bedford, 1937, p. 28). "... Intervallar tissue of curved hexagonal-tubular lattices and by an inner wall with large pores leading upwards and inwards into the central cavity. ..."

Present diagnosis (after Hill 1965, p. 123, Debrenne 1969a, p. 314 and restudying typical material).

The outer wall is simple, with an irregular mesh as pore-pattern. The inner wall has one row of short tubes per intertaenial and inter-synapticular space, leading upwards and inwards into the central cavity. Intervallum with pseudo-septa wavy in radial plane. The waves have angular crests and troughs, the side of which perforated by one row of regular round pores. The crests, the troughs and the pore-lines curve upwards and outwards from the inner wall. The crests of neighbouring septa are connected by synapticulae, the space between them being of the same size as the diameter of septal pores.

Discussion. The suggestion that *Pycnoidocyathus* could be the bulged form of *Flindersicyathus*, and for that reason should be considered as a sub-genus of *Flindersicyathus*, is made untenable by examination of typical material. In fact *Flindersicyathus* is junior synonym of *Pycnoidocyathus*.

Glaessnericyathus gen. nov.

Type species: *Bronchocyathus sigmoideus* BEDFORD and BEDFORD (1936). Holotype 86750, Princeton University (pl. 1, fig. 3).

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis. (R. and J. Bedford 1936, p. 25). Cups with straight non-porous septa and scarce pectinate tabulae. Outer wall with simple pores. Inner wall of annular type; the section of annuli is somewhat S-shaped, but with middle part oblique upwards and inwards, and α and β components nearly flat.

Discussion. As *Bronchocyathus* is an invalid name (Debrenne 1969a, p. 318), *aulax* TAYLOR having true *Coscinocyathus* tabulae, the forms with pectinate tabulae have to be placed in a new genus and a new family, which corresponds to Cyclocyathellidae Zhuravleva 1960 amongst Ajacicyathacea.

Systematic position. Family Glaessnericyathidae fam. nov. This genus is dedicated to Prof. M. F. Glaessner, University of Adelaide.

Metacoscinus BEDFORD and BEDFORD 1934

Type species by subsequent designation here: *Archaeocyathus retesepta* TAYLOR 1910. Holotype, University of Adelaide T1550 f.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford 1934, p. 6). "... The upper part strongly resembles Taylor's *Archaeocyathus retesepta*, but we have not felt justified in claiming identity without Professor Taylor's sanction and direct comparison of the type specimen. The probable relationship is indicated by our specific name 'reteseptatus' and, should the identity be admitted, the name would be *Metacoscinus retesepta* (TAYLOR). The genus may be defined as Metacyathidae with straight net like septa in the upper part, and with tabulae present."

Discussion. Having had the opportunity to compare *reteseptatus* BEDFORD with typical material of *retesepta* from Taylor's collection I can state that *reteseptatus* is a junior synonym of *retesepta*. Consequently, according to the International Code of Nomenclature art. 67 c. the type species of *Metacoscinus* is *retesepta* (TAYLOR).

Present diagnosis. Conical cups with sparse horizontal structures perforated by small circular pores, the skeletal part of which bearing tubercles. Radial septa built up by associated rods which have considerable opening between them, taller than wide. Outer wall with pores irregular outside. Inner wall with 2 rows of polygonal pores separated by thin skeletal mesh.

Systematic position. Family Metacoscinidae BEDFORD and BEDFORD 1936.

Metacyathus BEDFORD and BEDFORD 1934

Type species by subsequent designation by Bedford and Bedford 1936, p. 20: *Metacyathus taylori* BEDFORD and BEDFORD (1934, p. 5, fig. 30). Holotype: British Museum (Natural History) S 4185-7 (one specimen).

Original diagnosis (R. and W. R. Bedford 1934, p. 5-6). "... the genus may be defined as Metacyathidae in which a combination of septal and trabecular masses extends to the upper part of the cup, with strong development of vesicular (dissepimental) tissue."

After revision of type material (Debrenne 1969a, p. 355), "the holotype of *M. taylori* shows that the structures of the intervallum are disturbed by the occurrence of exothecal lamellae, but that, at other levels, the plates continue from one wall to the other. The porosity of the outer wall depends on the presence or absence of the exotheca; the inner wall has one vertical row of pores in the lower part of the cup, but two or more at the upper part, with probably a second wall".

The conclusion was that *Metacyathus* is a junior synonym of *Metaldetes*.

Metafungia BEDFORD and BEDFORD 1934

Type species: *Metafungia reticulata* BEDFORD and BEDFORD by monotype. Holotype: British Museum (Natural History) S 4184.

Original diagnosis R. and W. R. Bedford (1934, p. 5). "... Metacyathidae having numerous regularly arranged synapticalae in the upper part of the cup."

Emended diagnosis (R. and W. R. Bedford 1936, p. 16). "... Archaeos having definite though irregular and highly porous septa and numerous regularly arrayed synapticalae; in the base the central cavity is absent, its place being taken by trabecular and dissepimental tissue; the outer surface is wavy but is not thrown into prominent flange.

Present diagnosis (Debrenne 1969a, p. 362). "Cup with central cavity that becomes free of skeletal tissue late in its development. The walls are double-porous. The intervallum is crossed by straight taeniae, which have their pores arranged in lines curving upwards and outwards; numerous synapticalae join the taeniae. The vesicular tissue is present at the base and in contact with tersioid outgrowths." The inner wall has one pore, generally divided into two parts by a thin skeletal vertical rod.

Systematic position. Family Metafungiidae BEDFORD and BEDFORD 1934.

Metaldetes TAYLOR 1910

Type species by monotypy: *Metaldetes cylindricus* TAYLOR (1910, p. 151, pl. 15, fig. 86). Holotype, University of Adelaide T 1592 A-F.

Lower Cambrian, Wilson, near Quorn. Wilkawillina Limestone. South Australia.

Original diagnosis (Taylor 1910, p. 151). "A cylindrical organism . . . which is characterised by a striking change in structure during its growth. In the upper later portions it possesses a well-defined central cavity with a circular inner wall and regular septa, very coarsely perforate, which connect the inner and outer walls. A centimetre lower the septa are very irregular, though the inner wall preserves its definite outline. In the basal portions of the cup the inner wall is lost and the septa run right across the cup, apparently fusing at the centre with opposing septa . . ."

Present diagnosis. Solitary or colonial cups. From an apical part entirely filled up by skeletal elements (bars, plates, vesicular tissue) irregularly scattered, inner wall and central cavity are defined late in growth development. At the same time, intervallum irregular structures change into pseudo-septa, radial (sometimes bifurcated) with coarse round pores of irregular size, connected by dissepimental horizontal vesicles. Outer wall has one frame with large pores, screened by a second microporous sheath, linked to the frame by rods (described by Taylor as tridents). Inner wall also of double structure (Debrenne 1969b).

Discussion. The suggestion (Debrenne 1969a, p. 355) that *Metacyathus* and *Bedfordcyathus* are junior synonyms of *Metuldetes* is confirmed by examination of type material.

Systematic position. Family Metacyathidae BEDFORD and BEDFORD 1931.

Monocyathus BEDFORD and BEDFORD 1934

Type species: *M. porosus* BEDFORD and BEDFORD 1934 selected by subsequent designation by Bedford and Bedford 1936. Holotype: British Museum (Natural History) S 4140.

Original diagnosis (after R. and W. R. Bedford 1934, p. 2, fig. 1). "A conical tube, often somewhat waved by gentle annular constrictions. . . . Wall thin, pierced by very uniform and regularly arranged pores; the pores . . . are circular, and alternate as the rows are traced longitudinally but form a square pattern as the rows are traced diagonally; this is the most usual arrangement of pores in the inner wall of normal Archaeocyathinae. One specimen was noticed in which the rim at wide end is folded inwards to a depth of a little over 1 mm. and about the same distance inwards from the wall; this suggests that the wall may correspond to the outer wall of Archaeocyathinae. . . ."

Present diagnosis (Debrenne 1969a, p. 302). Small conical cups with a simple porous single wall and the vertical rows of pores in quincunx pattern.

Discussion. Okulitch (1950) Debrenne (1964) and Hill (1965) consider *Archaeolynthus* TAYLOR 1910 as an invalid name, as the type specimen was not designated by the author, and the reference material was destroyed by serial sectioning. The rim described by Bedford is not preserved in their various collections but Zhuravleva (personal communication) has discovered this feature in one specimen coming from a reference collection from Ajax Mine and interpreted it as the beginning of a "pelta" which could close up adult cups.

Systematic position. Family Monocyathidae BEDFORD and BEDFORD 1934.

Palmericyathellus gen. nov.

Type species by original designation here *Sigmofungia tabularis* BEDFORD and BEDFORD (1937, p. 29, fig. 115). Holotype S6746, Princeton University U.S.A. (Pl. 11, fig. 2).

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Diagnosis. Archaeocyatha with septa, synapticalae and tabulae. Outer wall with irregular polygonal pores, several per intersept. Inner wall with curved and bended canals, S-shaped, the aperture more or less hexagonal. Septa straight, pierced by small pores. The lines of pores and synapticalae are slightly curved from inner to outer wall. Tabulae frequent but irregularly spaced. They consist of microporous sieves developed between septa and special synapticalae arranged in horizontal planes, instead of along quincunxial lines as all the others.

Systematic position. Family Sigmofungiidae BEDFORD and BEDFORD 1936. This genus is dedicated to Prof. A. P. Palmer, State University of New York at Stony Brook.

Paracoscinus BEDFORD and BEDFORD 1936

Type species by original designation: *Paracoscinus mirabile* BEDFORD and BEDFORD (1936, p. 18, fig. 85-86). Holotype P 988, South Australian Museum, Adelaide.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford, p. 18, fig. 85-86): "... The genus may be tentatively defined as having clearly defined septa and closely set curved tabulae, growing from an irregular base; the outer wall consisting of a finely porous layer supported by an irregular trabecular mesh. ..."

Present diagnosis. Conical cup, the apex of which has an unperforate outer wall, radial septa and central cavity with alveoles. Adult stages with septa and close-set tabulae; pores in vertical and horizontal lines in septa, quincunxial in tabulae. Septa radial, thickened at their inner part. Tabulae nearly flat at the inner wall, arched outwardly. Outer wall with a frame of coarse rectangular to polygonal pores, covered by microporous sheath. Inner wall with vertical ridges corresponding to septa and 2 rows of square pores per intersept.

Systematic position. Family Paracoscinidae fam. nov.

Paranucyathus BEDFORD and BEDFORD 1937

(for *Paracyathus* BEDFORD and BEDFORD 1936 on EDWARDS and HAIML 1948)

Type species by monotypy: *Paracyathus parvus* BEDFORD and BEDFORD (1936, p. 17, fig. 76). Holotype P 992, South Australian Museum, Adelaide.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford 1936, p. 17, fig. 76). "Small conical forms in which the base is filled with irregular trabecular tissue without inner wall or septa, the outer wall having small irregular pores; within a short distance of the base clearly defined radial septa, inner wall and central cavity appear, and the small irregular outer wall pores are replaced by large and regular pores."

Present diagnosis. Conical cups with two walls, radial stout septa and generally vesicular tissue in the intersept. They developed from a base which consists of radial plates near the outer wall, ending and anastomosing in the central part of the internal space, surrounded by non-porous or irregularly porous outer wall. Inner wall and central cavity appear very soon. The outer wall has 2 rows of irregular pores per intersept, which may coalesce to form a rectangular one, or they may be protected by secondary thickening of their skeletal borders. One row of simple pores per intersept at the inner wall, regular and in quincunx. Septa radial, stout, with pores of less area than skeleton, irregular in size and arrangement. Vesicular tissue generally present.

Systematic position. Family Paranucyathidae fam. nov.

Pinacocyathus BEDFORD and BEDFORD 1934

Type species by monotypy: *Pinacocyathus spicularis* BEDFORD and BEDFORD (1934, p. 4). Holotype: British Museum (Natural History) S 4149.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (after R. and W. R. Bedford 1934, p. 4, fig. 21). "Conical tubes. . . . The outer wall consists of an open network. The principal members are a series . . . of vertical rods evenly spaced around the circumference of the wall; these rods, whilst for the most part lying at the periphery, dip occasionally a short distance inwards, they are united by short cross members which more frequently lie horizontally but may be inclined; in grinding away the surrounding matrix it was noticed that a few very short branch rods projected outwards from the wall. The inner wall cannot be fully seen . . . apparently it consists of an open network. . . ."

Present diagnosis (DeBrenne 1969a, p. 342). "Two-walled cups with inter-vallar rods. The outer wall is formed by a scaffolding of vertical pillars connected by horizontal or slightly oblique rods. The inner wall is probably a regular net. Oblique or radial horizontal rods in the intervallum."

Discussion. This loosely-spaced framework is unknown in any other Archaeocyatha. Intervallum structures resemble those of *Chouberticyathus* DEBRENNE, but the walls are different.

Systematic position. Doubtfully in Family Dictyocyathidae TAYLOR 1910.

Polycoscinus BEDFORD and BEDFORD 1937

Type species by original designation: *Polycoscinus contortus* BEDFORD and BEDFORD (1937, p. 37, fig. 157). Holotype by monotypy 87217, Princeton University.

Lower Cambrian, Paint Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1937, p. 37). "The genus is formed for the reception of two meandering, branching *Coscinocyathus* like forms from the 'Paint Mine'. . . ."

Present diagnosis. Colonial forms with porous septa and rather remote porous tabulae. The outer wall has vertical and horizontal fluting (independent from tabulae). It is of double-porous structure: coarse frame pores, covered outwards by thin microporous sheath. Septa have distant vertical rows of pores. Flat tabulae, the pores of which being the same diameter as those of septa but closed. Inner wall with vertical ridges towards the intervallum and cupules at the lower part of cup towards central cavity.

Discussion. The second species *complexus*, which has the same branching way of growth has simple walls. It belongs to *Pluralicoscinus* DEBRENNE 1963.

Systematic position. Family Polycoscinidae DEBRENNE 1964.

Putapacyathus BEDFORD and BEDFORD 1936

Type species by original designation: *Putapacyathus regularis* BEDFORD and BEDFORD (1936). Holotype 86699, Princeton University.

Lower Cambrian, Putapa Gap, South Australia.

Original diagnosis (after R. and J. Bedford 1936, p. 24). ". . . The outer wall has on its inner surface regular vertical ridges, . . . these are crossed by narrower bars . . . and each oblong space so formed is again divided by vertical partition so as to give an external surface regularly and quadrately porous. The inner wall . . . has a series of vertical ridges in two series, which alternately project into the intervallum and the central cavity. . . . Each ridge has a vertical series of 'stirrup-pores', so arranged that opposite each external ridge is an internal row of pores,

whilst all pores communicate with tangential perforations in the centre line of the wall, thus giving a clear though indirect communication between central cavity and intervallum. Regularly arranged, nearly horizontal tabulae . . . with numerous somewhat irregular pores. No septa or other structures representing septa are present, . . ."

Present diagnosis. Cup with no septa in the intervallum but only horizontal tabulae with rather regular pores; the two walls are built to the same pattern, the outer wall being thinner and more close-set. Each wall consists of a double cone of pillars in alternating positions so that opposite each pillar is an interspace. Their cross section is triangular, the apices of the internal pillars pointing towards the intervallum and those of the external ones towards the exterior. The bases of the triangles are in the middle portion of the cross section of the wall. The two circles of pillars are connected by regularly spaced horizontal rods.

Systematic position. Family Putapacyathidae BEDFORD and BEDFORD 1936.

Pycnoidocoscinus BEDFORD and BEDFORD 1936

Type species by original designation: *P. pycnoideum* BEDFORD and BEDFORD (1936, p. 19, fig. 87). Holotype P.990, South Australian Museum Adelaide.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis R. and W. R. Bedford (1936, p. 18, fig. 87). "Forms with numerous arched tabulae of unusual type; the outer wall has a finely porous layer supported by a trabecular mesh, and is thrown into large and prominent corrugation resembling those of *Pycnoidocyathus*. . ."

Present diagnosis. With the exception of septa, the basic structures have two kinds of pores. Those of the outer wall are bounded by septa and more or less horizontal bars, and subdivided by rods which are parallel or oblique with regard to septa; they are screened outwardly by a microporous sheath. The inner wall has one rectangular pore per intersept with vertical ridges at each septum, and aligned (the tabulae lean against some of these horizontal bars). The pores may be subdivided by crude septa which are limited to the non-porous part and sometimes also by irregular oblique rods. Micropores may develop between these frames but not as an independent sheath. Septa radial with outer and inner part thickened and non-porous; while the middle part is thin and with numerous regular small pores. Tabulae strongly arched in their inner part, and gently sloping towards the outer wall. Pores are reticular as in *Retecoscinus* and with additional skeletal partitions parallel to septa.

Systematic position. Family Pycnoidocosciniidae fam. nov.

Pycnoidocyathus TAYLOR 1910

Type species by subsequent designation (Bedford and Bedford 1939, p. 78): *Pycnoidocyathus synapticus* TAYLOR (1910, p. 132, pl. 12, fig. 69). Holotype: University of Adelaide T 1587 B-C.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis TAYLOR (1910, p. 131). "A large conical tube, with a central cavity . . . The outer wall is bulged into a series of annulations so that the outer diameter reaches 80 mm. and contracts to 50 mm. at regular intervals. This gives the organism the appearance of a stout tube strengthened by flanges. The inner wall is not influenced by the annulations. The septa are rather wavy and tend to anastomose in the peripheral portion. They are usually strengthened by very definite synaptics, resembling those in many corals. . ."

Present diagnosis. Outer wall simply a porous mesh. Inner wall with one large pore per intersept, as a short oblique tube, leading upwards and inwards into the

central cavity. Intervallum filled up by radial pseudo-septa, more or less wavy in radial plane, connected by synapticalae which define lines curving upwards and outwards from the inner wall; their curve turn nearly horizontally into flanges where present.

Discussion. There is no fundamental difference of structure between *Flindersicyathus* and *Pycnoidocyathus*. The revision of material coming from the type locality yields any number of intermediate forms between gently annulated forms and strongly bulged ones, and between intervallum structures with angulate crests and troughs, and more flat pseudo-septa. The differences observed are related to the size of the animal.

Systematic position. Family Pycnoidocyathidae OKULITCH 1950.

Rhizacyathus BEDFORD and BEDFORD 1939

Type species by monotypy: *Protopharetra radix* R. and J. BEDFORD (1937, p. 28, fig. 107 A.B. 86619, Princeton University.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford, p. 28). "... The outer wall is thick and clearly defined, but pores cannot be made out. ... The interior is occupied by an anastomosing mass of bars. The bars are circular in section, but flattened, with rounded corners; their direction is sloping, but they approach a longitudinal rather than a transverse orientation.

Emended diagnosis (R. and J. Bedford 1939, p. 69). "... This has the structure neither of a regular Archæocyath spitz nor of a transversely partitioned Metacyathine spitz. ... The form may perhaps be regarded as one modified from *Monocyathus*."

Discussion after revision. The small conical forms called *Rhizacyathus* may be part of "tersioid" outgrowths. The longitudinal orientation of bars and their connections are very similar to those of "*Tersia*". *Rhizacyathus radix* is not an independent form of "*Archæocyathus*" and has to be considered as invalid.

Other forms called "*Rhizacyathus*" by the Bedfords are *Archæopharetra*, with vertical plates and inner wall.

Rozanovicoscinus gen. nov.

Type species: *R. fonini* sp. nov. pro *Cadniaeyathus asperatus* BEDFORD and BEDFORD (pro parte) 86614, Princeton University.

Diagnosis. Cylindrical cups with vertical fluting the furrows corresponding to the septa. Septa and tabulae with round quincunxial pores of the same type. Tabulae flat, frequent, but irregularly spaced. Outer wall with round regularly spaced pores, in quincunx. Inner wall with short honeycomb tubes two or three per intersept.

Systematic position. Family Erisimacoscinidae DEBRENNE 1964. This genus is dedicated to Dr. A. Yu. Rozanov (Geological Institute Academy of Science of the U.S.S.R., Moscow).

Sigmocoscinus BEDFORD and BEDFORD 1936

Type species by original designation: *Sigmocoscinus sigma* BEDFORD and BEDFORD (1936, p. 24, fig. 98). Holotype 86686, Princeton University.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1936, p. 24, fig. 98). "The genus may be defined as cups with regular straight septa, tabulae of the normal *Coscinoeyathus* type and continuous annular sigmoid plates inside the inner wall. ..."

Present diagnosis. The intervallum consists of rectangular loculi built by normally porous septa and tabulae. The outer wall has several rows of pores per intersept in horizontal lines. The lower edges of pores project outwardly as peaks which could be fused laterally, forming somewhat annular scales. Inner wall of true annular sigmoidal pattern.

Discussion. The structure of the outer wall differs from that of the one of *Coscinocyathus didymoteichus*: several pores per intersept partially underlined by secondary element arising from the outer edge of pores.

Systematic position. Family Sigmocoseinidae BEDFORD and BEDFORD 1939.

Sigmocyathus BEDFORD and BEDFORD 1936

(*Hemistillicidocyathus* TING 1937)

Type species by original designation: *Coscinocyathus didymoteichus* TAYLOR (1910, p. 140). Holotype, University of Adelaide T 1606 B-D (one specimen).

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1936, p. 23). "... Large turbinate cups with numerous straight septa, without synapticalae or tabulae, the inner wall, or both wall, possess continuous annular sigmoidally-curved plates; growth is from an irregular base of trabecular and vesicular tissue which fills the central cavity and obliterates the septa. ..."

Present diagnosis. Conical cups; numerous straight septa, with few widely spaced or no pores. No tabulae. Inner wall and outer wall with sigmoid annular plates, the middle part of the S being nearly horizontal, and the element covering almost entirely the apertures between two adjacent septa. The annuli of the outer wall are gently wavy horizontally, narrower and more crowded than those of inner wall.

Discussion. There is no proof that these forms grow a *Metacyathus*-like apex, the only specimen (230 A in Princeton collection) on which the Bedfords built their hypothesis is not connected with an adult stage of *C. didymoteichus* and does not present characters which could be interpreted as *didymoteichus*.

Systematic position. Family Sigmocyathidae ZHURAVLEVA 1960.

Sigmofungia BEDFORD and BEDFORD 1936

Type species by monotypy: *Sigmofungia flindersi* BEDFORD and BEDFORD. Holotype P.963, South Australian Museum.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and W. R. Bedford 1936, p. 16, fig. 82). "Archaeos having clearly defined radial septa which may be more or less irregular, with numerous synapticalae; the inner wall pores are in vertical rows, each pore being separated from those above and below it by a sigmoidally curved plate. ..."

Present diagnosis. Straight and stout radial septa perforated by small regular round pores. Numerous synapticalae, specially in the outer $\frac{2}{3}$ part of intervallum. Outer wall with regular alveoles, restricted outwardly by processes rising from the boundaries of pores. Inner wall with one pore tube per intersept, which becomes sigmoid into the central cavity; they are settled in quincunx.

Discussion. The holotype has a central cavity secondarily filled by well developed vesicular tissue and skeletal plates connected to the inner wall. The skeletal plates become thinner and are resolved into thin connected bars during the development of the cups. Vesicular tissue still present. This feature is known only in one specimen, the other being free of endothecal tissue.

Systematic position. Family Sigmofungiidae BEDFORD and BEDFORD 1936.

Spirilicyathus R. and J. BEDFORD 1937

Type species by original designation: *Spirilicyathus tenuis* BEDFORD and BEDFORD (1937, p. 30, fig. 118). Holotype 86752, Princeton University.

Lower Cambrian, Paint Mine, South Australia.

Original diagnosis (R. and J. Bedford 1937, p. 30). "... The outer wall has irregular pores, formed by anastomosis of the underlying septal elements. The septa are built of a series of radial and longitudinal rods and are connected by tangential rods or 'synapticulae'. As seen in transverse section, the septa often run fairly straight from inner to outer wall, but they also often bifurcate and anastomose particularly near the outer wall. The inner wall is a definite layer with small circular pores, about two rows to the intersept. As far as we know the form grows from a spitz having essentially the same character."

Emended diagnosis (R. and J. Bedford 1939, p. 73). "These small forms which appear to grow from a spitz of *Alphacyathus* type present features intermediate between *Dictyocyathus* and the regular septate forms, having partial and rudimentary septa; the outer wall is more irregular than is usual in members of this order.

Present diagnosis. Microporous outer wall covering spurs rising from the outer part of septa. Septa rather clearly defined, generally radial, but also branching. The synapticulae are piled up in each interseptum. Simple inner wall with one or two rows of pores per intersept.

Discussion. The intervallum is filled up by septa and synapticulae rather than by anastomosing rods, but the lack of material and the smallness of holotype do not permit to point out clearly the true structure of this genus. As far as we know, young stages still have radial structures.

Systematic position. Family (doubtfully) Metacyathidae.

Stapicyathus DEBRENNE 1964

Type species: *Archaeocyathus stapipora* TAYLOR (1910, p. 118) by original designation of Debrenne (1964, p. 127). Holotype T. 1591, University of Adelaide, South Australia.

Original diagnosis (after Taylor 1910, pl. VII, fig. 37-38, Fig. 14). "Shape a conical beaker more or less elongated; occasionally bulged inward on each side giving an hour-glass cross section. . . . Outer wall somewhat thinner than the inner wall and perforated by numerous regular pores. . . . Septa regular and numerous. . . . A very characteristic feature is that the only pores visible are a single series of large openings where the septa join the inner wall . . . (stirrup-pores). Inner wall is somewhat thick, with one row of large pores along each inner septal edge as already described. . . . No pores in the intervals between septa."

Present diagnosis. Conical cups with outer wall thin and regularly porous. Inner wall thicker, with only one row of stirrup-pores in front of each septa. No other pores between them. Septa completely non-porous except the vertical row of pores which are part of stirrup-pore of the inner wall.

Discussion. According to Okulitch (1943, p. 60) the type of *Archaeocyathellus* is lost. The specimens I had opportunity to study from the type locality are poorly preserved and did not correspond to the description of holotype, having many rows of pores at the outer wall and sometimes porous septa, when preserved, the inner wall has stirrup-pores. Until further studies have been carried out we cannot be sure that *Stapicyathus* is sub-genus of *Archaeocyathellus*, as has been supposed. Meanwhile it will be considered as an independent genus. Its single row of pores relates it to *Robustocyathus*.

Systematic position. Family Robustocyathidae.

Stillicidocyathus TING 1937

Type species by original designation; *Coscinocyathus aulax* TAYLOR (1910, p. 139). Holotype T 1605 B, University of Adelaide, South Australia.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (Ting 1937, p. 367). Körper kegelförmig oder zylindrisch, grosswüchsig. Die Innenwand fehlt. Die Rinnenringe mit vollständigen Seitenwänden, aber modifiziert. Der Zapfenbesatz ist nach aussen verschoben und ihre Spitzen sind stark nach innen eingerückt. Pseudo-septen zahlreich. Pseudoböden immer vorhanden und in weiten Abständen aufeinanderfolgend.

Present diagnosis. Gently wavy cone. Outer wall with regular alveoles. Inner wall annular, the section of which is S-shaped, strongly bent upward so that the apertures between adjacent septa are nearly closed up by two successive annuli. Septa radial with small remote pores. Scarce tabulae of normal type (Debrenne 1969b).

Discussion. *Stillicidocyathus* differs from *Satairocyathus* only by the shape of its annuli.

Systematic position. Family Stillicidocyathidae TING 1937.

Syringoenema TAYLOR 1910

Type species, by original designation: *S. favus* TAYLOR (1910, p. 153, pl. XIV, fig. 78-79). Holotype No. T 1597, University of Adelaide.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (Taylor, p. 153). "A pipe-like cone with a diameter at the wider end of about 20 mm. It consists of an outer and inner wall—which are often papillate—between which extends a series of hexagonal tubes closely packed together, which radiate from the inner wall like the spokes of a wheel. The tubes have a diameter of about a millimetre and their axes are horizontal. The tube walls are perforated by fairly large pores which place them in communication with each other. The central cavity is narrow. . . ."

Present diagnosis. Unfortunately the type specimen is very badly preserved and the outer wall is missing; the diagnosis is based on the holotype and on paratypes T 1550, T 1558 which are of best preservation.

Conical cup, the intervallum of which consists of a packing of hexagonal porous tubes. The axes of the tubes are horizontal and radial from the outer wall for three-quarters of their length. Then they become narrower and bend downwards near the inner wall with a more or less acute angle. The outer wall is made of the apertures of hexagonal tubes, which are closed by rods rising from the angles and the middle part of skeletal boundaries. These rods bear spherical granules, which give the outer surface a regularly dotted appearance. The inner wall corresponds to the aperture of the narrow parts of the bending tubes. The pores are protected by denticular plates, rising from the lower edge of the pores: when in line, the plates join their neighbours and form an annular-like structure. When in quincunx, the joining could be oblique or interrupted.

Systematic position. Family Syringoenematidae TAYLOR.

Thalamocyathus GORDON 1920

Type species by elimination by Ting 1937, p. 368: *Archaeocyathus trachealis* TAYLOR (1910, p. 125), lectotype Taylor 1910, pl. 8, fig. 47 (7-8) chosen by F. Debrenne (1969, p. 262) No. T 1555, University of Adelaide, South Australia.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (Ting 1937, p. 367-368). Körper kegelförmig oder zylindrisch, klein oder gross. Innenwand fehlt. Den Innenrändern der Pseudosepten sitzt ein System von Rinnenringen an. Die beiden Seitenränder der Rinnenringe sind gleich gut ausgebildet. Die Zapfen, die ihnen an der Mitte der Unterseite ansitzen, sind einfach und gerade. Die Pseudosepten sind zahlreich-Pseudoböden fehlen. Balkennetzwerk kann vorhanden sein oder fehlen. Die Gattung *Thalamocyathus* muss daher auf *Archaeocyathus trachealis* beschränkt bleiben.

Present diagnosis. Conical or cylindrical cups. The outer wall has simple pores, in regular quincunx, which could be narrowed outside. Inner wall annular, V-shaped with an obtuse angle. Radial septa with few or no pores. No pectinate tabulae (Debrenne 1969b).

Discussion. The lectotype has been chosen amongst Taylor's syntypes because of its better preservation, and because it agrees with the general conception of the genus. There are no pectinate tabulae amongst Taylor's syntypes. A very badly preserved specimen (pl. I-1) bears some siliceous granules which could be doubtfully regarded as a trace of tabulae. Consequently, *Gordonicyathus* ZHURAVLEVA 1960 is a junior synonym of *Thalamocyathus*.

Systematic position. Family Cyclocyathellidae ZHURAVLEVA 1959.

Zonacyathus BEDFORD and BEDFORD 1937

Type species by monotypy: *A. retetallum* BEDFORD and BEDFORD (1934, p. 2, fig. 6). Holotype: British Museum (Natural History) S 4147.

Lower Cambrian, Ajax Mine, Beltana, South Australia.

Original diagnosis (R. and J. Bedford 1937, p. 36). "Archaeocyathina with fine regularly arranged outer wall pores, closely set porous septa and an inner wall consisting of a reticular mesh of considerable thickness without a defined porous lamina. . . ."

Present diagnosis (Debrenne 1969a, p. 314). Porous two-walled cups with non-porous—or few porous—septa. The outer wall has regular pores. The inner wall has branching pore-tubes; the initial tube is located in the middle of each interseptum and then branches so that the secondary tubes open in front of each septa. The tubes may lengthen and curve into the central cavity.

Systematic position. ?family Ethmophyllidae Okulitch 1943.

APPENDIX

Notes on type species of new genera *Cricopectinus*, *Ethmopectinus* and *Rozanovicoscinus*.

Cricopectinus dentulus gen. sp. nov. Pl. I, fig. 1.

1919—*Ethmophyllum dentatum* TAYLOR (pro parte): p. 129, pl. XIV, fig. 89.

Holotype: University of Adelaide T 1589 B.

Type-locality: Ajax Mine, Beltana, South Australia.

Age: Lower Cambrian.

Description: as for the genus.

Dimensions:

Cup

Height (pars)	23.5 mm.
Diameter	10.5 mm.
Intervallum	1.62 mm.
Interseptum	0.16 mm.

Outer wall		
Number of pores per interseptum	2	
Diameter of pores	0.95 mm.	
Skeletal partition	0.05 mm.	
Thickness	0.08 mm.	
Inner wall		
Number of pores per interseptum	1	
Diameter of pores	0.16 mm.	
Skeletal partition	0.32 mm.	
Thickness	0.8 mm.	
Septa		
Non-porous except		
1 vertical row of pores near the outer wall.		
Thickness	0.08 mm.	

Discussion. Only one specimen known. It differs from *Cyathocriscus dentatus* by the presence of pectinate tabulae.

Ethmopectinus walteri gen. sp. nov. Pl. I, fig. 2.

Holotype: 86762 Princeton University.

Paratype: 86755 Princeton University.

Type-locality: Ajax Mine, Beltana, South Australia.

Age: Lower Cambrian.

Description: as for genus.

Dimensions:

Cup			
Height (pars)	Holotype	Paratype	
Diameter	9 mm.	11 mm.	
Intervallum	8 mm.	12 mm.	
Interseptum	1.8 mm.	2 mm.	
Intertabulum	0.21 mm.	0.16 mm.	
Parietal coefficient	unknown (1 tabula)	5.7 mm.	
	9	unknown	
Outer wall			
No. of pores per interseptum	3-4	3	
Diameter of pores	0.03-0.05 mm.	0.03-0.05 mm.	
Skeletal partition	0.03 mm.	0.03 mm.	
Thickness	0.05 mm.	0.05 mm.	
Inner wall			
No. of pores per interseptum	1	1	
Diameter	0.16 mm.	0.21 mm.	
No. of horizontal lamellae per pore	3	5	
Distance between lamellae	0.05 mm.	0.03 mm.	
Thickness of lamellae	0.05 mm.	0.03 mm.	
Septa			
Non-porous except 4 rows of pores near the outer wall		non-porous	
Diameter of pores	0.03 mm.		
Thickness	0.05 mm.	0.05 mm.	

Discussion. Only two specimens known. They differ from *lineatus* by the presence of pectinate tabulae. This species is dedicated to Dr. M. R. Walter, University of Adelaide.

Rozanovicoscinus fonini gen. sp. nov. Pl. II, fig. 1.

Holotype: Princeton University 86614.

Type-locality: Ajax Mine, Beltana, South Australia.

Age: Lower Cambrian.

Description: as for the genus.

Dimensions.

Cup

Cup

Height (pars)	60 mm.
Diameter	14.5 mm.
Intervallum	
along a septa	2.75 mm.
at the middle of furrow	3.15 mm.
Interseptum	1 mm.
Intertabulum	2.3 mm.
Parietal coefficient	2.4

Outer wall

No. of pores per interseptum	6-8
Diameter	0.1 mm.
Skeletal partition	0.09-0.1 mm.
Thickness	1 mm.

Inner wall

No. of pores per interseptum	2-3
Diameter of pores	0.2 mm.
Skeletal partition	0.1 mm.
Thickness	0.20 mm.

Septa

No. of pores per intervallum	8-10
Diameter of pores	0.09 mm.
Skeletal partition	0.16 mm.
Thickness	0.1 mm.

Tabulae

No. of pores per interseptum	5-8
Diameter of pores	0.06 mm.
Skeletal partition	0.06 mm.
Thickness	0.1 mm.

Discussion. Placed by R. and J. Bedford with paratypes of *Cadniacyathus asperatus* because of vertical fluting of outer wall; the specimen described above differs from it by the presence of tabulae and the simplest porosity of inner wall. This species is dedicated to V. D. Fonin (Paleontological Institute, Academy of Science of the U.S.S.R., Moscow).

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PLATE 1

- 1—*Cricopectinus dentulus* gen. sp. nov.—holotype T 1589 B U.A. $\times 4.2$.
- 2—*Ethmopectinus walteri* gen. sp. nov.—holotype 86762 P.U. $\times 4.2$.
- 3—*Glaessnericyathus sigmoideus* (Bedford) holotype 86750 P.U. $\times 4.2$.
- 4—*Dailycyathus margarita* (Bedford) paratype 87215 P.U. $\times 4.2$.
- 5—*Dailycyathus margarita* (Bedford) holotype 87214 P.U. $\times 14$.

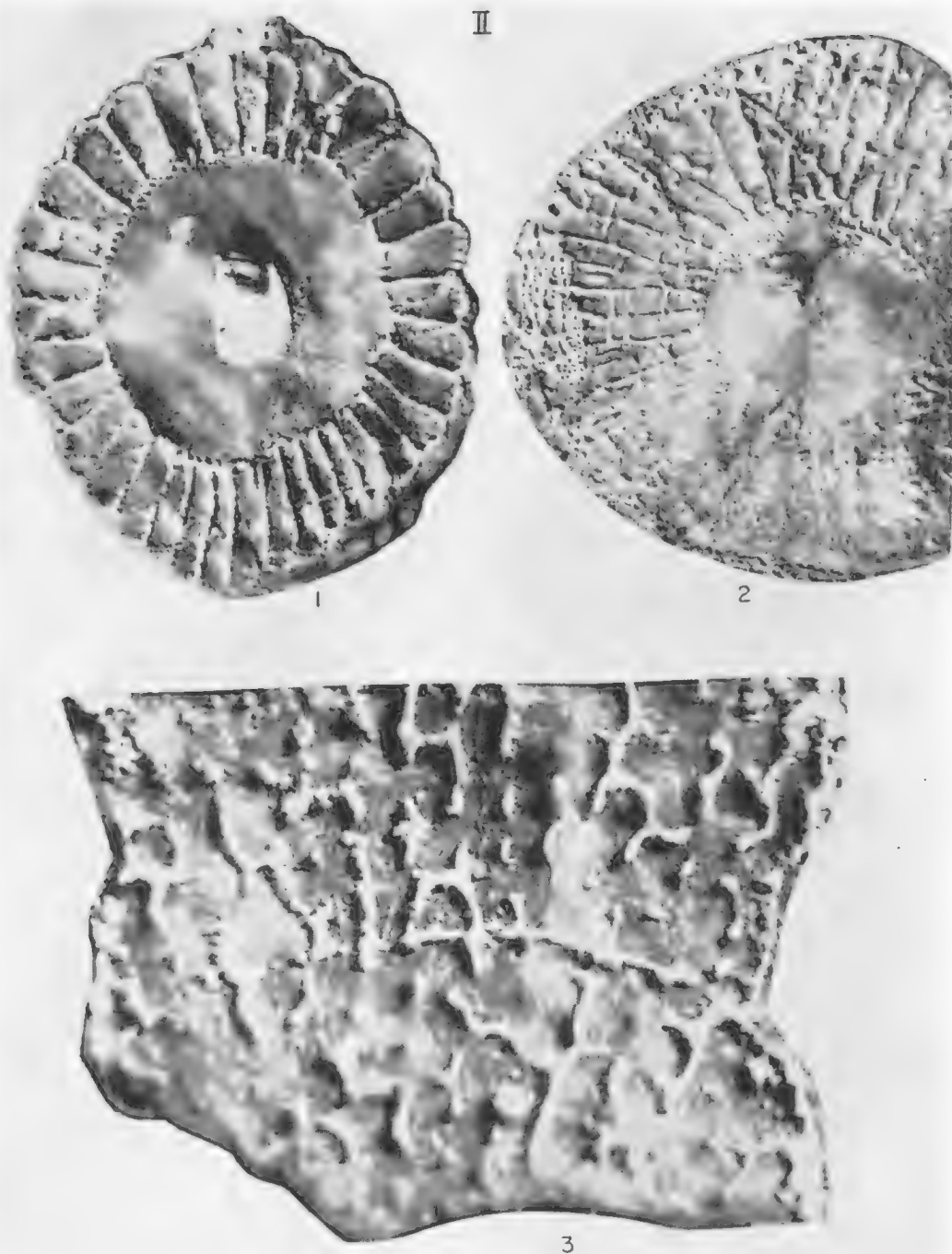


PLATE 2

- Fig. 1. *Rozanovicoscinus fonini* gen. sp. nov. holotype 86614 P.U. $\times 4.2$.
 Fig. 2. *Palmericyathellus tabularis* (Bedford) holotype 86746 P.U. $\times 4.2$.
 Fig. 3. *Flindersicoscinus tabulatus* (Bedford) holotype 86666 P.U. $\times 7$.

A NEW SPECIES OF PELARGONIUM L'HER. EX AIT. IN SOUTH AUSTRALIA

*BY ROBERT F. G. SWINBOURNE**

Summary

A description is given of a new species of *Pelargonium* L'Her. ex Ait., *P. renifolium* sp. nov. in South Australia. Type specimen is cited and some notes on comparison with *P. grossularioides* (L.) L'Her. ex Ait., *P. australe* Willd. and *P. littorale* Hugel are made.

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INTRODUCTION

During a visit to Mt. Lofty Botanic Garden, the plant here described was found growing in a newly cleared area of land and duly collected. Examination revealed it to be a new species not previously described and further investigation indicated it to be more widespread although previously unrecorded in this state.

Pelargonium renifolium R. Swinbourne sp. nov.

Herbaceous perennials, diffusae, procumbentes, radicibus longis, surcularis promptae; folia reniformia vel cordata, aliquantum lobata, 2-5 cm. longa, supra pilis sparsis, petiolis usque ad 21 cm. longis; caules florentes usque ad 30 cm. longi, pedunculus multiflorus, calyx 3 mm., pilis longis sparsis, petala 5, 3 mm. longa, alba vel pallido-rosea, 2 supra rubro-maculata cum striis duplicibus, cetera angustiora cum stria singulari, tubus nectarii brevissimus, antherae 5, rostrum fructus usque ad 2 cm., semen laeve.

Perennial herbs, irregularly and widely spreading, procumbent, roots long, suckering readily; leaves reniform to cordate, somewhat lobed, 2-5 cm. long, with sparse hairs on the upper surface, and with petioles up to 21 cm. long; flowering stems up to 30 cm. long; peduncle many-flowered; calyx 3 mm. with long sparse hairs; petals 5, 3 mm. long, white to pale pink, 2 upper spotted red with 2 marks, 3 narrower with single marks, nectary tube very short; anthers 5; fruiting beak up to 2 cm.; seed smooth.

- Range: Moist areas of Mt. Lofty Ranges and south eastern South Australia.
Habitat: Sclerophyll association, sandy loam full of humus, and under shrubs. Accessible to moisture, in gullies near creeks or run off areas.
Typification: Holotype: Rhodo Valley, Botanic Garden, Mt. Lofty, R. Hill et R. Swinbourne 28th August 1969 (Herbarium of Cultivated Plants, Botanic Garden, Adelaide, South Australia No. 4462.) Herb. No. AD96947080. (Plate 1.)

DISCUSSION

Material of the plant presently under discussion and that of *Pelargonium littorale* Hugel and *P. australe* Willd. deposited in the State Herbarium of South Australia were compared and found to differ in the following characters; both *P. littorale* and *P. australe* are much more hairy overall than *P. renifolium* sp. nov. This new species being almost glabrous approaches *P. grossularioides* (L.) L'Her. ex Ait. a complex South African species which however differs in leafshape and the flowers.

* Botanic Garden, Adelaide.

P. grossularioides (mentioned by Carolin, 1961) and further discussed by Moore (1955) has small cordate, dentate leaves and small red-purple flowers, whereas the leaves of *P. renifolium* sp. nov. are more reniform than cordate and the flowers though small are white to pink, spotted and marked in deeper colour on the upper petals. Black (1963) describes *P. australe* as a "perennial, the stems rather stout, sub-erect . . ."; the new species also acts as a perennial but it is a rather weak, slender stemmed plant. It also has a habit of suckering which is not recorded in those other species mentioned above.

The new species can be keyed among those *Pelargonium* spp. listed for South Australia (in Eichler, 1965, p. 198).

- (3) Fertile stamens 4-5 Perennial stems short, not succulent.—(Hairs on the calyx long and spreading-villous)

. *P. littorale* 2

Fertile stamens 4-5

Perennial stems long, nectary tube short not as long as calyx, habit of suckering from roots, 2 upper petals spotted and marked. (Hairs on the calyx long and sparse.)

. *P. renifolium* sp. nov.

Selection of specimens examined at AD,

- South East* R. C. Nash 8.XI.1969 "The Turkey Farm", ca. 1.6 km. north of Nangwarry (AD 96948270).
 Mrs. J. Turner 17.X.1968 Beachport ca. 27 miles N.W. of Millicent (AD 97008089).
 R. Swinbourne 20.X.1969 12 miles north of Coonalpyn (AD 97007446).
 T. Davey 20.II.1970 Salt Creek ca. 38 miles south of Meningie (AD 97008090).

ACKNOWLEDGMENTS

I would like to thank Mr. John Carrick, State Herbarium, Botanic Garden, Adelaide for assistance with this paper, Mr. Ron Hill for observations in the field at type locality, and Horticultural Students of Botanic Garden, Adelaide for their observations on field trips.

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Herb AD 96947080



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STATE HERBARIUM OF SOUTH AUSTRALIA
ADELAIDE

Leg Collector's No.
Date

GEOMORPHOLOGY OF THE SOUTHERN PART OF THE ARCOONA PLATEAU AND THE TENT HILL REGION, WEST AND NORTH OF PORT AUGUSTA, SOUTH AUSTRALIA

BY C. R. TWIDALE, JENNIFER A. SHEPHERD AND ROBYN M. THOMSON¹

Summary

The region between the head of Spencer Gulf and the southern tip of Lake Torrens is occupied by a series of plateaux and plains. Within this region the geomorphology of the Beda valley and of the Tent Hill area is described in detail. Remnants of surfaces of low relief of similar ages occur in both areas. The Arcoona plateau-Tent Hill surface is considered to be of Mesozoic age. The Beda and Corraberra pediment surfaces, which in places carry silcrete, are probably of middle Tertiary age. Around Lake Torrens only one Pleistocene-Recent level exists, but near Port Augusta three have been identified. The ancient land surfaces are preserved by virtue of protective cappings of quartzite, silcrete and gibber.

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The region between the head of Spencer Gulf and the southern tip of Lake Torrens is occupied by a series of plateaux and plains. Within this region the geomorphology of the Beda valley and of the Tent Hill area is described in detail. Remnants of surfaces of low relief of similar ages occur in both areas. The Arcoona plateau-Tent Hill surface is considered to be of Mesozoic age. The Beda and Corraberra pediment surfaces, which in places carry silerete, are probably of middle Tertiary age. Around Lake Torrens only one Pleistocene-Recent level exists, but near Port Augusta three have been identified. The ancient land surfaces are preserved by virtue of protective cappings of quartzite, silerete and gibber.

INTRODUCTION

In the course of a reconnaissance in late 1967 a hitherto unmapped occurrence of silerete was noted in the Beda Valley, near the southern extremity of Lake Torrens (Fig. 1). The stratigraphic ages of sileretes have been closely determined in adjacent areas (Wopfner, 1960; Wopfner and Twidale, 1967). As the geomorphic relationship of the plain bearing the silerete and other erosional and depositional plains both in the Beda Valley and in neighbouring regions is quite clear, the silerete surface forms an invaluable morphostratigraphic unit, or geomorphic time marker, by means of which the relative ages of other surfaces can readily be established. The Beda Valley and environs were mapped in September 1968², and the mapping units there determined were traced southwards into the Tent Hill region, to the west and north of Port Augusta, which was surveyed during 1969.

Beda Valley and Environs

(a) *General setting:* The Beda valley lies west of the Lake Torrens lineament (Johns, 1968), and is underlain by essentially flat-lying Precambrian sediments. They were deposited on the western stable shelf of the Adelaide geosyncline (Stuart Stable Shelf of Sprigg, 1952) but, as they overlap on to the margin of the resistant Westralian Shield, suffered little or no deformation during the Palaeozoic orogeny responsible for the Flinders-Mt. Lofty ranges fold belt. The highest member of the Precambrian sequence in the Beda valley area is the Arcoona Quartzite, a flaggy sandstone which displays cross-bedding in many places. Beneath the Arcoona Quartzite is a thick sequence of purple shales, glauconitic in parts, and with intercalations of sandstones, micaceous sandstone and gypsum, the latter apparently primary.

The Arcoona Quartzite forms a resistant capping and, where it is preserved, gives rise to prominent plateaux and mesas such as Dutton Bluff and Beda Hill. The Beda Creek and its several tributaries have breached this caprock and extensively eroded it, so that it now occurs only in scattered outliers. The present morphology of the area is due to the dissection of the caprock and the exposure

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² This part of the investigation was supported by a grant from the Royal Society of South Australia Research and Endowment Fund.

of the less resistant strata beneath the Arcoona Quartzite by the Beda Creek drainage system.

(b) *Morphology*: Four distinctive landform assemblages have been identified and mapped (Fig. 2).

The Arcoona plateau remnants stand some 200 metres above the river channels in Dutton Bluff (280 m), Cairn Hill, Camp Hill, Lake View and Beda Hill (200 m). The Arcoona Quartzite buttresses the escarpments, but does not form the plateau surface: cross-bedded sandstones occur above it, with the result that the plateaux tops tend to form gentle topographic domes (Pl. 1, Fig. 1).

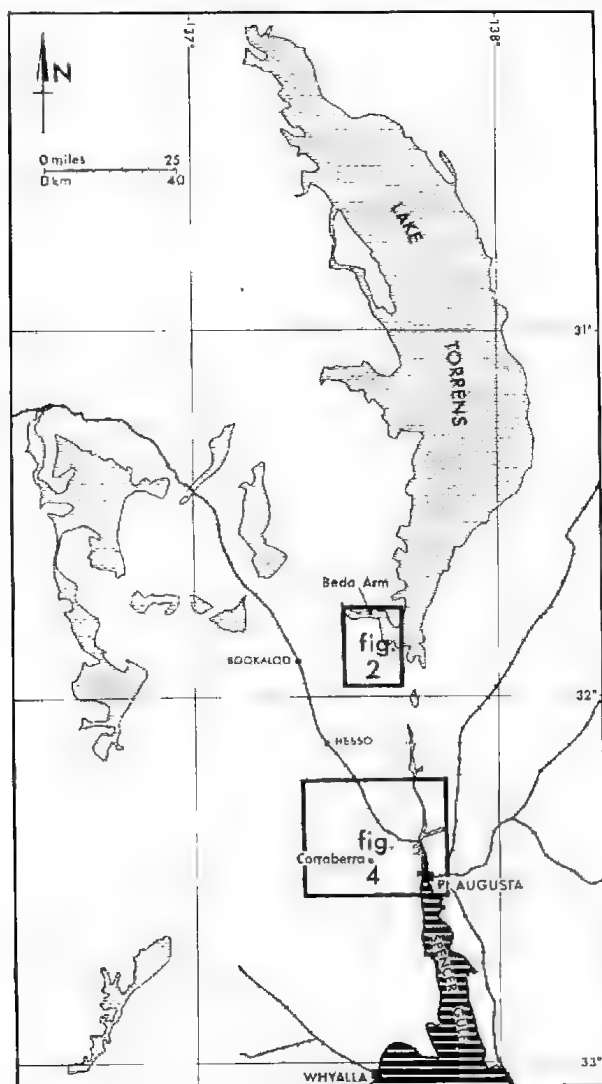


Fig. 1. Location map.

The bounding scarps below the quartzite outcrops are steep and faceted, with particularly resistant strata supporting prominent structural benches which are continuous over considerable distances as at Camp Hill and near Sues Gap. The micaceous sandstones in places display unusual patterns of weathering, and gnammas or weather pits (*see* e.g. Twidale and Foale, 1969, p. 79).

The *Arcoona hills* occur extensively where the massive Arcoona Quartzite has been removed by stream erosion. Aerial reconnaissance suggests that near the western margin of Lake Torrens this is the dominant landform assemblage. The hills are low and rolling, with concave-convex sigmoidal slopes of the order of 7° to 8° average inclination. Drainage channels are widely spaced and the relief amplitude is of the order of 50 to 60 m. Outcrops are few. Instead, there is a virtually continuous cover of stony clay soils which are derived from the shales and mudstones and which display good gilgai development.

The *Beda pediment* is dissected, but extends from the footslope of the escarpments bounding the Arcoona plateau to the present river valleys where the toe of the pediment stands 6 to 7 m above the river channels. The surface slopes vary from 4° near the scarp foot, to 1° to 2° near the valley axes. In many areas the former scarp foot between the escarpment and pediment has been dissected by streams which have exploited the zone of intense and deep weathering commonly developed there (Pl. 1, Fig. 2). In the few localities where the dissection has not yet penetrated, the pediment joins the scarp in a narrow zone of curvature, the piedmont angle (see Twidale, 1967).

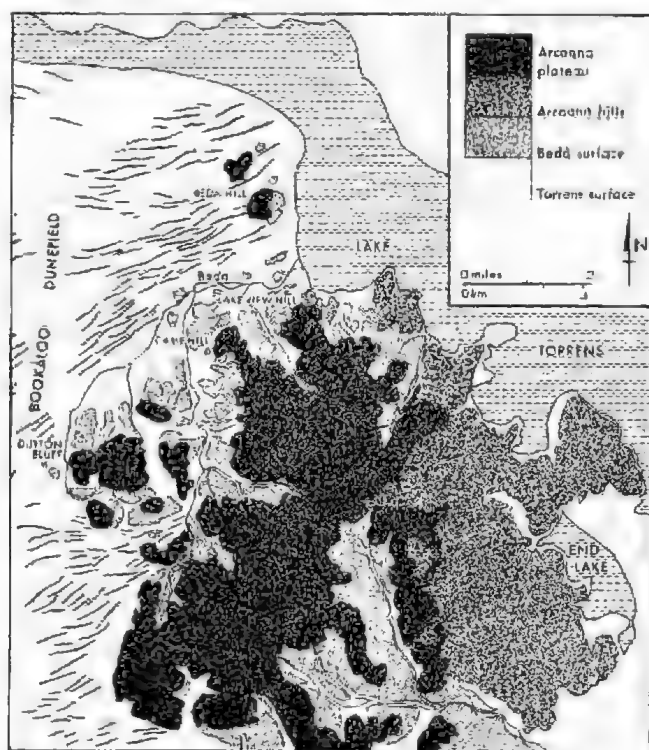


Fig. 2 Morphological map of Beda Valley and environs.

Quartzite lag, comprising mainly small slabs, forms a protective desert pavement. Clays derived from the shales below the Arcoona Quartzite display gilgai on the middle pediment slopes, but both at the scarp foot and at the toe of the pediment, silcrete has accumulated (Fig. 3: Pl. 1, Figs. 1 and 3). That in the scarp foot is characteristically in the form of coatings between 0.5 cm and 30 cm thick around unaltered quartzite blocks; it borders joint planes and in places the boulders display superficial reversion or desilication. The silcrete in the valley floors, on the other hand, is more massive (up to 2 m thick), is columnar, contains rounded though faceted pebbles, and is underlain by weathered shales and

then by unaltered purple shales with gypsum. This topographically lower silcrete is either absent or is little developed at the toe of some pediment remnants but most display the twofold distribution described.

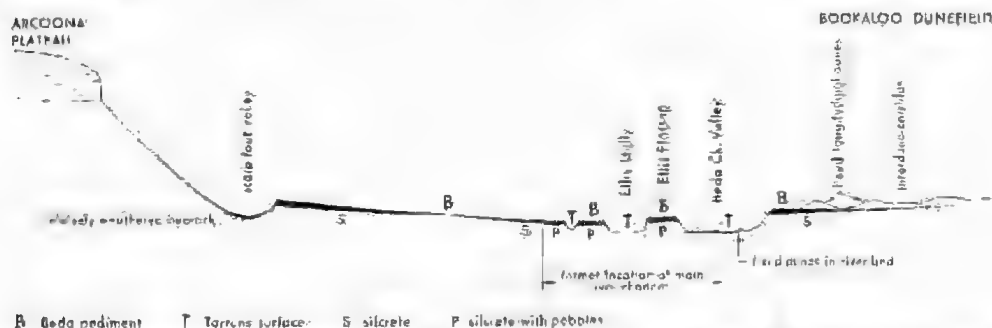


Fig. 3. Diagrammatic section of the Beda pediment between Camp Hill and Beda Creek.

The *Bookaloo dune field* consists of fixed red dunes standing up to 6 m above the interdune corridors. They are about 70 m from crest to crest and trend roughly NNE and SSW in the southwest of the survey area, but to the north run ENE-WSW. Claypans occur in the interdune corridors and a few intermittent, short streams flow to these centres of local drainage along the corridors and in some instances across the dunes. The dune sand is dominantly siliceous with a few grains of mica and feldspar; the quartz grains average 0.4 to 0.5 mm and are rounded to subrounded. Most of the grains have an iron oxide coating.

The dunes overlie the silcrete surface in the Beda valley. This relationship can be observed in many places, as for example a few metres west of the camp-site (Fig. 2).

The *Torrens plain* is essentially that associated with the present Beda Creek and its tributaries. The plain is of limited extent, being restricted to the channel of Beda Creek, and the channels and very narrow valleys of its several tributaries. The channel of Beda Creek is braided and in many places bounded by bluffs up to 7 m high. Some of these are of silcrete and it is clear that in the vicinity of Ellis Gully (Fig. 2), slight inversion of relief has occurred (Fig. 3). The silcrete of Ellis Gully is alluvial, and this was clearly the old valley floor: the silcrete-capped plateaux, both to the north and south of the present Ellis Gully, slope toward the depression. The present river however flows to the south of the gully, in the zone not so heavily indurated by silcrete. Fields of fixed dunes up to 2 m high occur in many places. This riverine plain merges with a narrow lowland bordering Lake Torrens. Here occur coastal foredunes, principally of gypsum (kopi dunes) as well as low, isolated mounds and salt flats. The salt surface is in places underlain by more than 80 m of Quaternary sediments (Johns, 1968).

(c) *Sequence of events*: The Arcoona plateau, the Beda pediment and the Torrens plain are all surfaces of low relief which, since they cut across various members of the Precambrian sequence, are of erosional origin. The three surfaces occur at quite distinct elevations and are separated by more-or-less steep escarpments, so that the landform assemblage presents a stepped appearance. None of them displays evidence of having been inundated by the sea, by lake waters or by thick sequences of alluvium. Thus the higher Arcoona surface is evidently of greater antiquity than the Beda surface, which is in turn older than the Torrens surface. The latter is of recent age but lack of fossiliferous superficial deposits, genetically associated with the two older plain remnants, precludes the possibility

of dating them directly. The longitudinal dunes of the Bookaloo field in the Beda Creek area occur mainly on the Beda pediment, though they spill over on to the Torrens plain near Bada Hill. Thus all that can be said concerning their age is that they postdate the period of silcrete development.

In summary the following sequence of events can be reconstructed:—

1. Erosion of Arcoona surface.
2. Major lowering of baselevel; stream rejuvenation, erosion of Bada pediment; development of silcrete; weathering of scarp foot zone.
3. Accumulation of Bookaloo dune field.
4. Slight negative baselevel movement, dissection of Bada surface, and development of narrow Torrens plain; local accumulation of dunes, lake and riverine deposits.

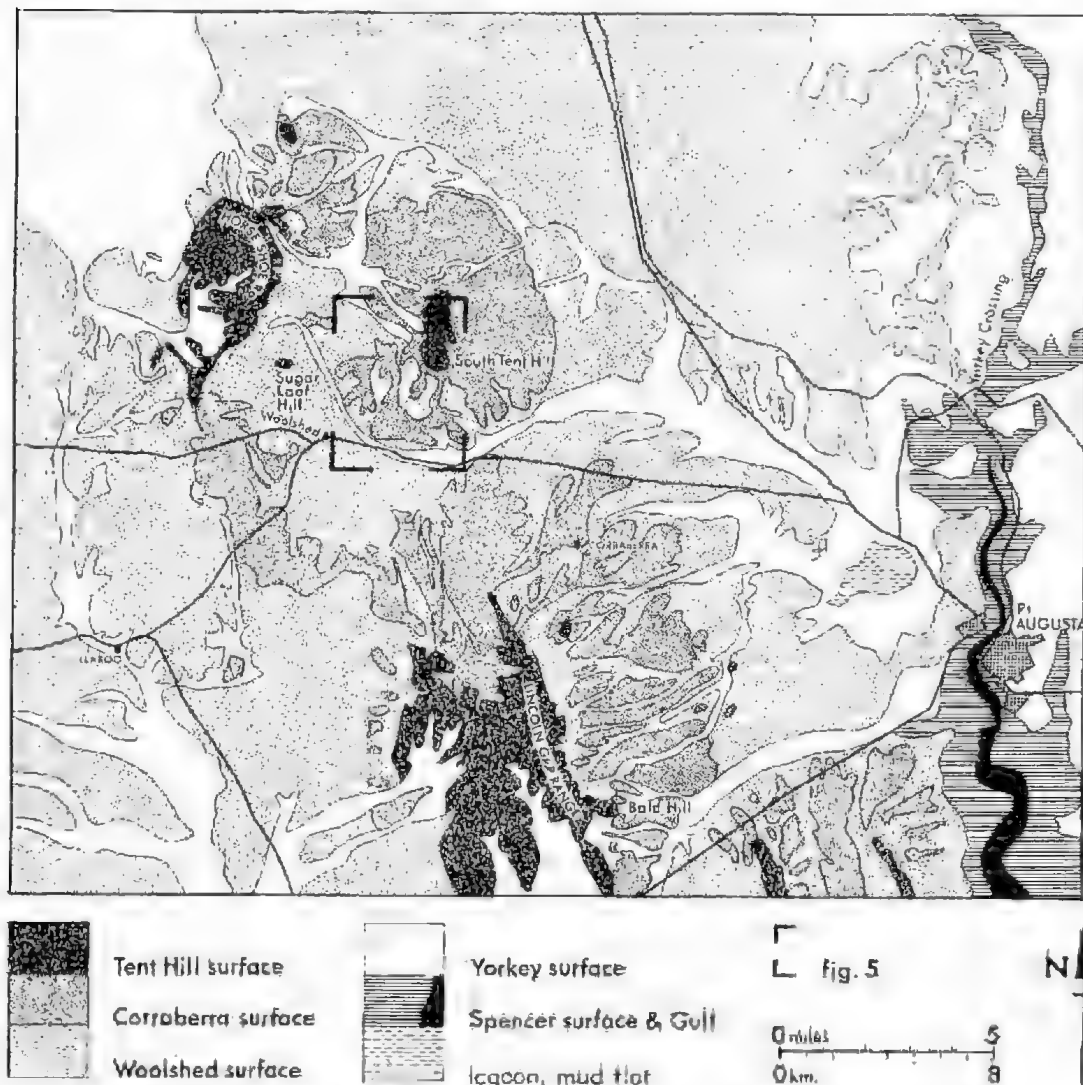


Fig. 4. Morphological map of the Tent Hill region (location at Fig. 5 shown).

The Tent Hill Region

(a) *General setting:* The Tent Hill region mapped during this investigation comprises the assemblage of plains and plateaux north and west of Port Augusta (Fig. 4). Field mapping did not extend south of the Eyre Highway. The landform assemblage has evolved on a sequence of flat-lying Precambrian sediments which overlap onto the Gawler platform, and which are the approximate equivalents of the sediments of the Beda Creek area and of the Marinoan beds extensively exposed in the nearby Flinders Ranges.

The sequence includes two prominent resistant sandstones, the Simmens Quartzite and the Corraberra Sandstone, which are interbedded with siltstones and shales. The landform assemblage of the Tent Hill area reflects the disposition of the sediments and their differential weathering and erosion by streams, which have graded to various baselevels through geological time.

(b) *Morphology:* The Tent Hill region consists of a series of stepped erosion surfaces which cut at low angles across the near-horizontally disposed strata, and which are separated in most places by precipitous scarps. The lower surfaces however in some areas merge imperceptibly one with another. The surfaces are shown in Fig. 4 and are described in sequence from highest to lowest.

The *Tent Hill* plateau surface is preserved in prominent plateaux, mesas and buttes (Pl. 2, Figs. 1 and 2) which are sufficiently numerous and widespread to suggest that they are part of a formerly contiguous surface. The plateaux stand some 250-260 m above the principal plains and attain heights 300-330 m above sea level. Most are capped and protected by Simmens Quartzite and are bounded by steep faceted scarps, many of which display structural benches. In detail no one stratum caps the plateau; the surface cuts across many individual beds and is therefore of erosional type.

The steep bounding scarps surrounding the Tent Hill surface lead down to quite steep debris slopes (inclination 10° to 15°) which merge imperceptibly with pediments inclined at 3° to 4° to the horizontal, though becoming gentler toward the axes of the valleys. These smooth, gently sloping pediments, which cut across various members of the argillaceous sequences, form the *Corraberra surface*. The Corraberra pediment is notable for the silcrete developed discontinuously upon it. Silcrete has been mapped in adjacent areas to the west (Dalgarno, Johnson, Forbes and Thomson, 1968) and west and north of Hesso (Fig. 1), but many of these occurrences in the Tent Hill region have not previously been recorded. The most massive silcrete occurs on the toes of the Corraberra pediment. Here the silcrete contains small rounded quartzite pebbles, and is probably a silicified alluvium. Silcrete is also quite well developed in scarp foot situations as, for example, near Corraberra H.S. and on the southern side of South Tent Hill. In the latter region it also occurs as long ribbons extending down-slope from the scarp foot zone along stream beds. In several areas the Corraberra pediment is separated from the backing escarpment by scarp foot valleys (Figs. 4 and 5, Pl. 2, Fig. 2).

On the long pediment slopes between the scarp foot and the old valley axes, silcrete is absent. These long, gentle slopes are characterised by the development of gilgai and by the surface accumulation of gibber, most of which consists of sandstone fragments.

Where silcrete or sandstone underlies the Corraberra pediment, the slopes bounding the low plateau are steep, though only 4 to 5 m high. But where the gibber forms the surface the bordering slopes are more gentle and the next lower plain, the Woolshed pediplain, merges without pronounced break of slope with the Corraberra surface.

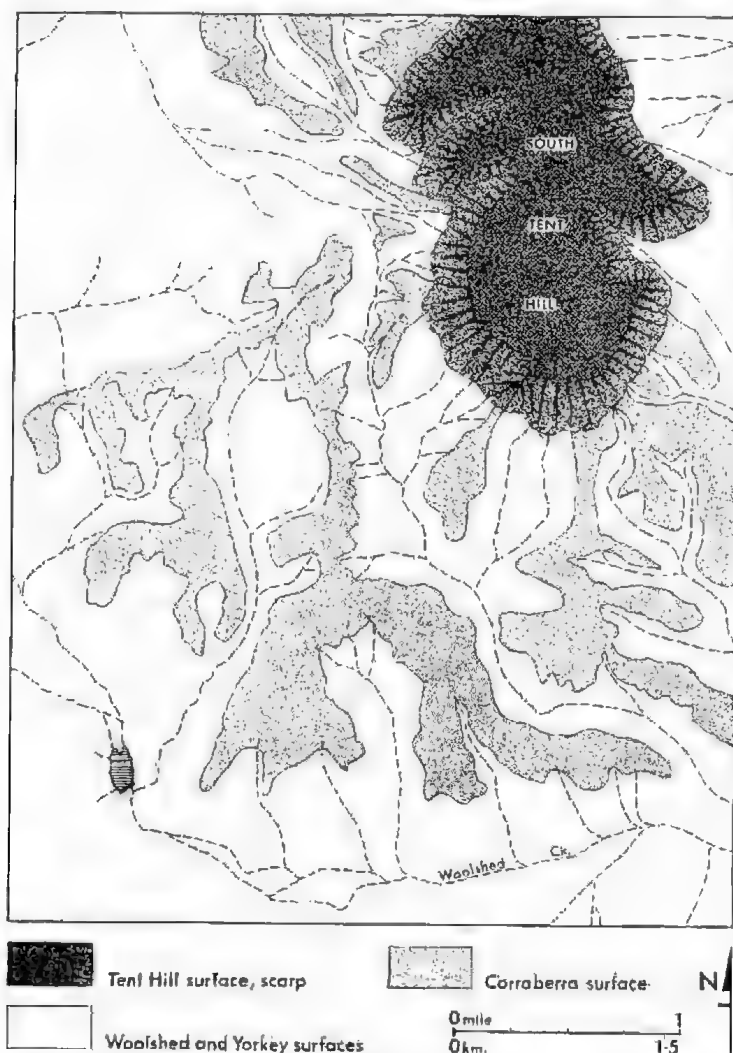


Fig. 5. Morphological map of Tent Hill South and the adjacent areas showing the scarp foot depression developed on its northern and western sides.

The *Woolshed pediplain* is the most extensive morphological unit in the Tent Hill region. It has a low inclination (1° to 2°) but nevertheless cuts across various lithologies. It is smooth and little dissected except near its eastern or Spencer Gulf margin, and is capped by a veneer of clay and gibber, prominent constituents of which are quartzite and silcrete. The Woolshed plain can on this account be considered a pediplain, though a sharp break of slope at the upper margin is not everywhere present.

As is the case with the Corraberra pediment, there are, within this erosional surface, areas of local deposition: some are riverine, some aeolian, the latter taking the form of fixed sand dunes. Gilgai are also widely developed on the surface and the streams draining this surface have cut deeply into the scarp foot zone of weathered rock. Near Corraberra H.S. laminated sediments and gypsum accumulations suggest that there was formerly impedance of local drainage in such a scarpfoot valley, giving rise to a shallow lake.

The Woolshed pediplain is dissected by streams. Most of the resultant valleys are shallow, but in the east they are deep and V-shaped in cross section. They open out to a narrow plain bordering the estuarine northerly extension of Spencer Gulf. This plain is called the *Yorkey surface*. It stands 3 to 30 m lower than the Woolshed surface. Claypans, including a large one northwest of Port Augusta (Fig. 4), are well developed on it, and there are also fixed dunes.

But the Yorkey surface has also suffered dissection and a narrow flat borders the estuary—the *Spencer surface*. It is some 6 to 7 m lower than the narrow Yorkey plain and displays mainly depositional forms, though there are some narrow erosional plains. Many of the estuarine and riverine deposits have been blown into dunes, and various areas of the estuarine flats have been isolated to form quite large lagoons.

(c) *Sequence of events*: The several planate surfaces described all cut across various and varied members of the Precambrian sedimentary sequence and are therefore essentially erosional in character. There has been considerable deposition on the Spencer surface, but apart from this, there is no evidence of incursions of the sea since the development of the surfaces. They can, therefore, be regarded as a stepped series in which the higher surfaces are of greater antiquity than the lower. The dunes which occur on the Woolshed, Yorkey and Spencer surfaces are not necessarily of similar age; all that can be said at present is that they formed subsequent to the erosion of the surfaces on which they stand. Thus the following sequence of events can be proposed:—

1. Erosion of Tent Hill plateau.
2. Deep erosion of streams and valleys, erosion of Corraberra pediment, patchy development of silcrete, and marked weathering of scarp foot zone.
3. Slight stream rejuvenation, denudation of Corraberra pediment over wide area, and extensive development of Woolshed pediplain; erosion of scarp foot valleys.
4. Moderate stream incision, and development of narrow plain along Gulf shore—the Yorkey surface.
5. Stream rejuvenation to level probably lower than that of present ocean surface.
6. Rise of sealevel, development of narrow plain in association with this level, and infilling of the arm of the sea—the Spencer surface.

It is to be emphasised that each of these stream rejuvenations continued its inland extension even after the next phase of incision had been initiated. Thus the surfaces continue to extend, the lower surfaces growing and migrating inland at the expense of the next higher. Hence, though the scarp foot valleys were prepared by localised weathering during the Corraberra period, and were first eroded during the Woolshed development, they continue to be extended; in this way, the area of both the Tent Hill and Corraberra surfaces continues to be reduced.

Denudation Chronology

(a) *General remarks*: A comparison of the surfaces of the Boda Valley and of the Tent Hill region strongly suggests that, though the latter region displays surfaces of limited extent close to the present sealevel and additional to those which occur in the former, the two areas have much in common. In particular the Arcoona and Tent Hill surfaces, and the Boda and Corraberra surfaces, appear equivalent. The Boda and Corraberra surfaces both bear silcrete, which can be traced, albeit discontinuously, between the two study areas. Thus some 3 km east

of Bookaloo R.S., within the Bookaloo dune field, silcrete is exposed in the Beda Creek track. Again, about 1 km south of Hesso H.S. sandstone exposed in a low plateau standing some 7 to 8 m above the plain level displays heavy surficial silicification and silcrete coatings. It thus seems probable that the silcrete of the Beda and Corraberra surfaces is part of the same development, and can therefore be used as a stratigraphic marker.

(b) *Age of silcrete*: It is just as important that the silcrete allows the only possibility of dating the surface on which it occurs, thus providing a time marker in the relative sequence of events.

Extensive sheets of silcrete occur in the northeast of South Australia and the adjacent areas of Queensland. There it is developed on strata which include the Winton Formation of upper Cretaceous and lower Tertiary age. Thus, the silcrete postdates the earliest Tertiary. On the other hand, the folded and dissected silcrete surface is in several places overlain by equivalents of the Etadunna Formation; the age of this Formation is problematic, though, in all likelihood, it is Pliocene. Thus the silcrete so widespread in central Australia developed in the middle Tertiary (Wopfner, 1963; Wopfner and Twidale, 1967).

This stratigraphically determined date was apparently confirmed by radiometric datings of a dolerite dyke alleged to intrude silcrete near Roma in south-eastern Queensland (Langford-Smith, Dury and McDougall, 1966); subsequent investigations, however, suggest that the stratigraphic relations of the two are questionable and that the significance of the 22.7 million years determined as the age of the dyke is unclear so far as the silcrete is concerned (Exon, Milligan and Day, 1967). A middle Tertiary silcrete has also been reported from the northern Willochra basin, in the southern Flinders Ranges (Twidale, 1966), the evidence again being stratigraphic.

Another silcrete of limited areal extent and of Pleistocene age has been reported from the area west of Lake Eyre (Wopfner and Twidale, 1967). It differs from the main, massive silcrete of central Australia in that the latter consists of quartz fragments and crystals set in a matrix of finely divided quartz while the matrix of the younger rock is opaline. It is reasonable and conceivable that all silcretes were originally opaline but that, with the passing of time, crystalline structure developed.

Both thin-section examination and X-ray diffraction show all the silcretes of the Beda and Corraberra surfaces to be wholly quartzitic. Thus all date from the middle Tertiary—probably Miocene—and indicate that the surfaces on which they are preserved are also approximately of this age.

(c) *Ages of erosion surfaces and correlations*: As the Bookaloo dunes rest upon the silcrete without themselves showing signs of secondary silicification, they, like the Torrens plain in the Beda Creek area, and the Woolshed, Yorkey and Spencer surfaces in the Tent Hills region, must postdate the middle Tertiary.

The Arcoona and Tent Hill surfaces, on the other hand, being higher, must be older than the middle Tertiary. The crucial evidence is reported by Johns (1968 pp. 7-13). The basal lacustrine sediments beneath the present bed of Lake Torrens, resting on folded Cambrian strata, are, on the evidence of their contained plant fragments, of Eocene age. Though the Torrens lineament is an ancient structure, stratigraphic evidence from beneath the present bed of Lake Torrens suggests that a phase of dislocation began in the Eocene, and continued through to the (?) Miocene. It seems likely that the major stream rejuvenation and dissection of the Arcoona plateau was initiated by faulting in the Eocene. Dissection of the broad valleys and the development of the Beda surface during the early Tertiary (Eocene-Miocene) contributed sediment to the lake then

occupying all, or part, of the Torrens sunkland. The Arcoona surface is thus essentially of late Mesozoic age.

Mesozoic surfaces border the Great Artesian Basin on its western side in the Peake and Denison Ranges, in the Granite Downs area (Wopfner and Twidale, 1967), in the ranges of central Australia (Mabbutt, 1965) and in northwest Queensland (Twidale, 1956). The Arcoona plateau-Tent Hill surface is probably part of this ancient land surface. The plateau surface, no doubt of similar age, extends south of the Tent Hill region to Whyalla and beyond, and can also be extrapolated into the Gawler Ranges, where it forms a summit surface. This conclusion is confirmed by the observed westward extension of equivalents of the Beda and Corraberra surfaces into the valleys and plains of the Gawler Ranges. Differential subsurface weathering and preparation of inselbergs on Eyre Peninsula occurred beneath this Mesozoic surface, which is much earlier than has previously been supposed (see Twidale, 1962).

It is suggested above that the disruption of the Arcoona plateau and the initiation of the Torrens sunkland were simultaneous events caused by down-faulting on the eastern side of the Torrens lineament. The erosion of the Beda surface with its associated silerete and of its southerly equivalent, the Corraberra surface, had occurred by the end of the Miocene, presuming this to be the age of the silerete. This coincides with the presumed end of Tertiary lacustrine sedimentation in Lake Torrens. Rejuvenation followed. Earth movements may again be responsible, as Pliocene or pre-Pliocene faulting along the Lincoln lineament, a complex fault zone linked to the Torrens lineament, has been suggested by Miles (1952). In the Lake Torrens area this caused renewed infilling of the depression, a process which has continued to the present time.

This later phase of tectonism may have initiated the development of the Woolshed pediplain in the Port Augusta region. In appearance and location with respect to the mid Tertiary silerete surface, the Woolshed surface is very similar to the gypsite surface extensively developed in the Lake Eyre basin (Wopfner and Twidale, 1967) and the two surfaces may be equivalent. However, in this southern area, because of its proximity to the sea, surfaces were developed additional to those represented in the Beda valley. They were associated with Pleistocene glacio-eustatic movements of sealevel, but it is not possible to be more precise. Reliance on vertical differences between surfaces is rendered dubious by the possibility of recurrent fault dislocation along the Torrens and Lincoln lineaments. Thus the Yorkey surface cannot be precisely dated simply by matching its present elevation with an appropriate alleged high Pleistocene sealevel. The Spencer surface is largely depositional and the amount of infilling, and hence the degree of sealevel lowering implied, is not known. All that can be said of the Yorkey and Spencer surfaces is that they are of Quaternary age.

Slope processes and behaviour

The preservation of these erosional surfaces, two of which are of great antiquity, is due to their hard cappings which induce a particular slope morphology and behaviour.

Each of the planate erosion surfaces of the Beda valley and Tent Hills regions bears a capping, the nature and effectiveness of which varies from surface to surface and from place to place upon the surfaces, but which in all cases exerts a protective function. These resistant cappings are of three types: —

1. Quartzites such as the Arcoona Quartzite in the Beda valley and environs and the Simmens Quartzite in the Port Augusta region.
2. Silerete.

3. Accumulations of more-or-less coarse stone, the well-known gibber. In the Beda region, the gibber consists predominantly of platy sandstones with desert varnish as well as quartzite fragments. These stones are concentrated as surface layers and originate in several ways:
 - (a) They may form as a result of mass movements on slopes (creep, slides, flows, avalanches), which cause coarse debris to migrate from exposures on the scarp slope and spread on to the upper pediment slopes.
 - (b) They may be derived from the weathering of bedrock; the coarser fraction may be relatively concentrated, due to the removal of fines from the surface by wind and running water.
 - (c) The wetting and drying of clays results in expansion and contraction and the development of gilgai (see e.g. Hallsworth, Gibbons and Robertson, 1955). During wetting and expansion both fines and coarse debris are thrust upwards, but when, after desiccation, cracking takes place, only the fines can return to depth down the comparatively narrow fissures, so that the fragments remain at the surface (Springer, 1958).

These cappings in varying degree protect the land surfaces on which they occur. The quartzites and sileretes are more effective in this respect than is the gibber, but even the latter is more resistant than the shales and siltstones beneath it. The cappings also influence slope morphology and behaviour. The presence of a resistant capping of quartzite or silerete ensures the development of a bluff and hence of a faceted slope. The quartzites are commonly underlain by siltstones or shales, the silerete by weathered sediments which are part of the silerete weathering profile. Thus weathering and erosion of the upper part of the slope, where the resistant strata outcrops, and the lower, underlain by weaker beds, are greatly in contrast. The lower slope, besides being built of inherently weaker beds, suffers marked weathering and erosion of the scarp foot (Twidale, 1962, 1967) which is consistently worn back and regraded, causing the subsequent undermining of the hard stratum at the bluff. This is manifested in the development of caverns, in the gradual unbuttressing of joint blocks in the bluff, in the downslope flowage of materials like gibber and, in general, on the collapse and recession of the bluff.

The undermining and collapse of the bluff leads to a particular mode of development of the debris slope. Below the points at which a bluff has collapsed, detritus from the bluff spreads out over the debris slope. The fragments derived from the bluff are coarse, and protect the soft rocks of the debris slope, while erosion, principally in the form of regressively eroding gullies, occurs on the unprotected sectors between these veneers of gibber. But this leads to the bluffs being undermined in new areas, to their collapse, and to the hitherto unprotected areas of slope being protected. Meanwhile, the earlier veneers have suffered weathering; and the washing out of fines causes the eventual downslope movement of the coarse fragments, so that these protected zones are again vulnerable to gullying and recession. In this way the focus of attack switches from place to place on the debris slope, and hence on the bluff. The process, which was described 30 years ago by Kirk Bryan (1940) was called by him *gully gravure*. Its effect is particularly well displayed beneath the silerete capping in Ellis Gully, and beneath the gibber veneer in Swallow Cliffs, both in the Beda Valley (Pl. 2, Fig. 3).

Thus, because of the particular slope budget (Tricart, 1957; Twidale, 1960) which prevails in these localities, faceted slopes tend to be developed and maintained, as long as the resistant capping persists. Slope retreat or recession which

is dominant in such lithological, structural and climatic environments continues until such time as the hard capping has been eliminated. Once this has been achieved, the bluff disappears, as has occurred in the Sugar Loaf, in the Tent Hill region, and slope decline becomes prevalent, as in the Arcoona hills region, unless or until the concentration of lag or gibber becomes sufficiently marked to produce a new protective veneer.

But because of the prevalence of scarp retreat, ancient erosion surfaces are preserved and are prominent features of the present land surface.

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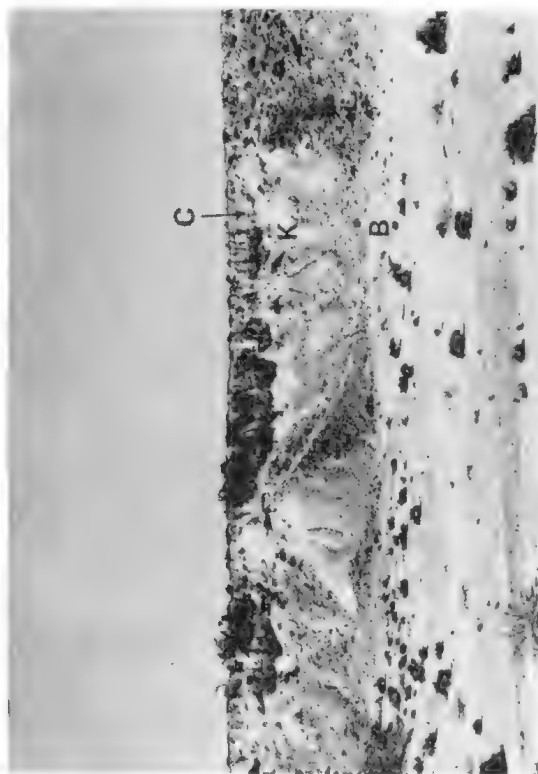
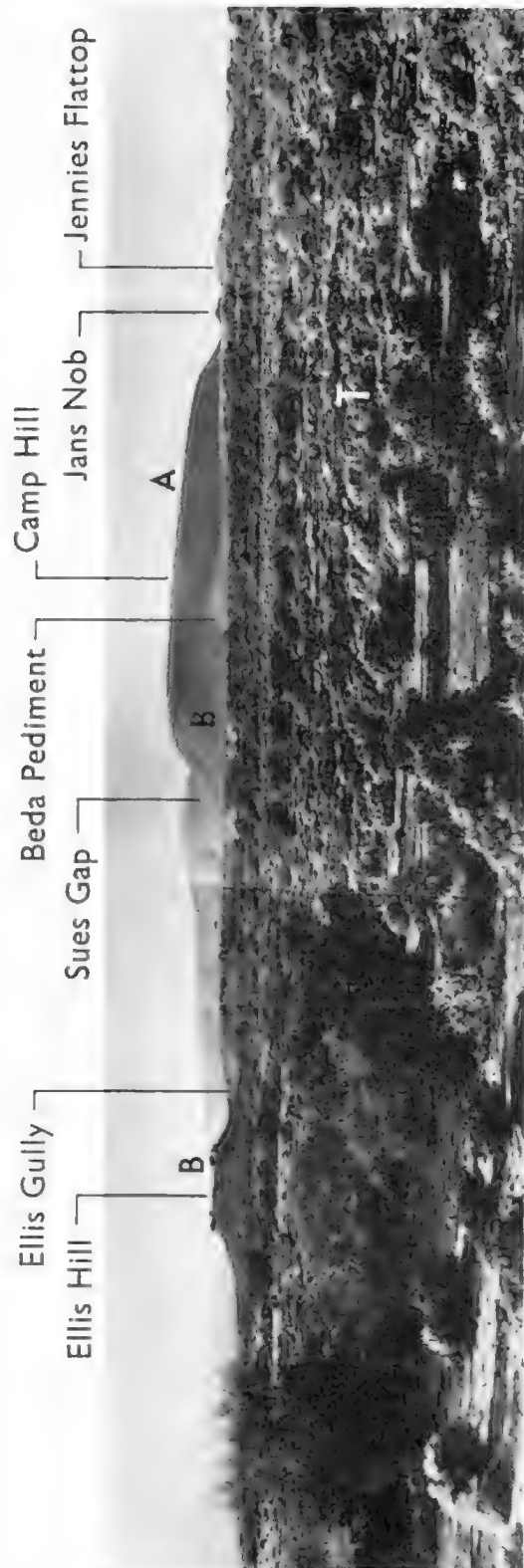
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PLATE 1

- Fig. 1. Panorama west from camp site (see Fig. 2). Note the domed plateau of Camp Hill (part of the Arcoona plateau—A); intense weathering, particularly the development of silcrete, beneath the toe of the pediment which represents the Beda surface (B) and of which Ellis Hill is part; and the lowermost or Torrens surface (T) which takes in the present channel of Beda Creek. (Photo. C. R. Twidale.)
- Fig. 2. Scarp foot valley on the east side of Camp Hill, with Jans Nob and Jennies Flattop on the right horizon. The patches of white beneath the three residual hills indicates intense weathering. (Photo C. R. Twidale.)
- Fig. 3. Silcrete profile exposed in Ellis Gully: columnar silcrete (C) is underlain by kaolinised rock (K) which, atypically, contains calcrete nodules. This is in turn underlain by bedrock (B). (Photo. C. R. Twidale.)

PLATE 2

- Fig. 1. Surfaces of low relief near Corraberra H.S. Note the scarp foot depression at the head of the Corraberra surface. (Photo. Robyn M. Thomson.)
- Fig. 2. Panorama of Tent Hill South, seen from the southwest (see Fig. 5). Note the plateau level of the Tent Hill surface (A), the pediment remnants of the Corraberra surface (B) and the moat or gutters formed by the strong scarp foot erosion of intensely weathered bedrock. These scarp foot valleys represent the Woolshed surface. (Photo. C. R. Twidale.)
- Fig. 3. Swallow Cliffs, near the mouth of Beda Creek, showing a stage in the operation of gully gravure. The superficial layer of river gravels (G) has in several places been undermined through the development of gullies in the soft shales exposed in the cliffs below. Hence gravel has poured down and partially filled these gullies (a), which are thus protected against erosion. The exposed shales (b) on the minor divides between gullies are more vulnerable and in future these will be eroded, gullies will form, the gravel will be undermined and will pour into the newly created depressions located between the present small valleys. (Photo. C. R. Twidale.)



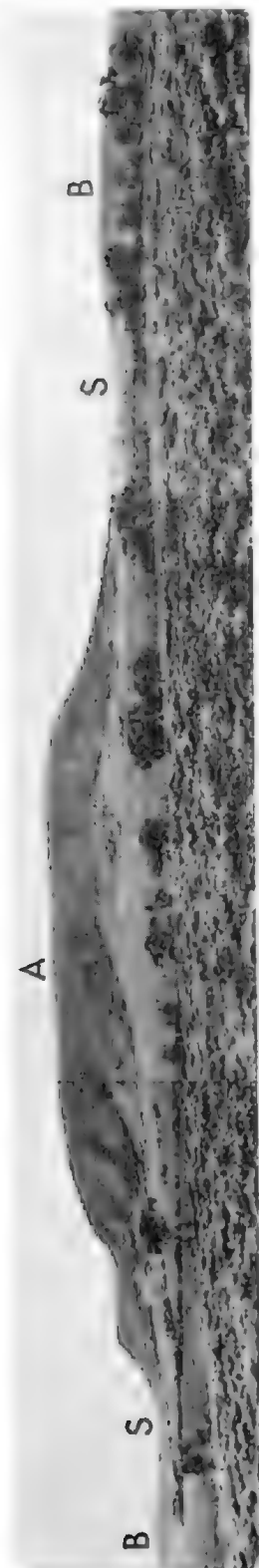


Fig. 2

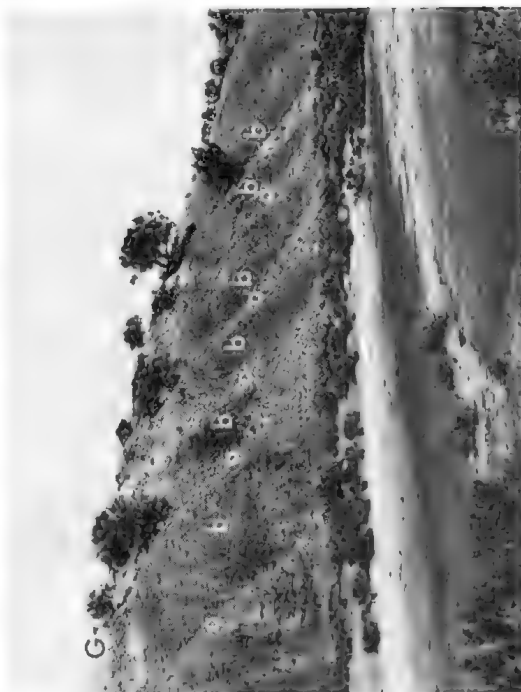


Fig. 3

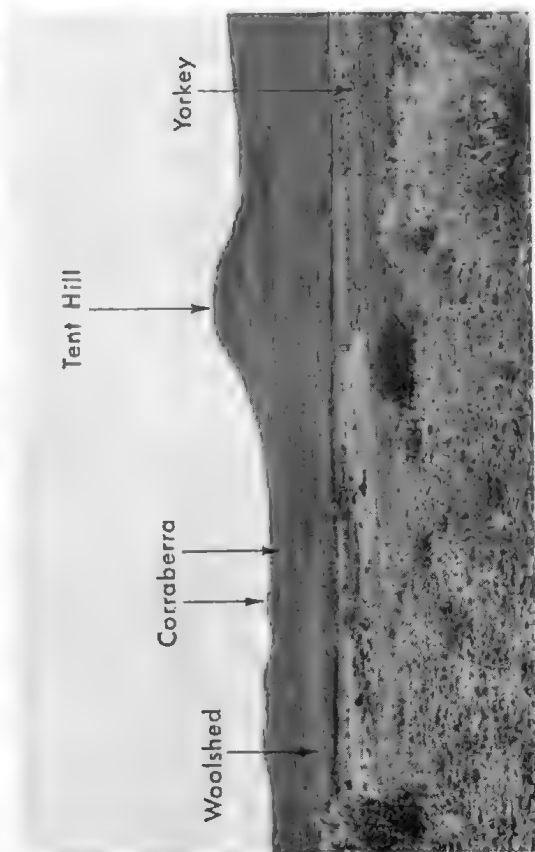


Fig. 1

PHYSICAL AND CHEMICAL LIMNOLOGY OF THE BLUE LAKE OF MOUNT GAMBIER, SOUTH AUSTRALIA†

BY A. TAMULY*

Summary

The Blue Lake at Mount Gambier occupies an area of 0.603 Km² (= 149 acres) at water level, and holds on the average, a volume of 36.8 million m³ (= 8090 million gallons) of freshwater. The mean and maximum depths of 61 and 77 metres are typical of the regular bowl-shaped basin, which resulted from the collapse of a volcanic crater about four thousand years ago. Indications of groundwater recharge and a daily passage of about 0.45 million m³ (= 100 million gallons) of freshwater through the lake are still tentative.

The change in water colour in November coincides with a Secchi Disk transparency of about 58% of that in September, and with an appreciable oxygen-deficit throughout the water column. Although the lake waters contain an equilibrium concentration of calcium, the ionic product never exceeds the solubility product of calcite at the observed pH and water temperature. This chemical state in water precludes precipitation of calcium carbonate, and as such, the change in water colour cannot be consequent to carbonate precipitation in the summer season. It is suspected that the blue colour is caused by fluorescence of dissolved organic matter, probably of allochthonous origin, which builds up seasonally in the upper layers of the lake waters.

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INTRODUCTION

The Blue Lake in the Mount Gambier district of South Australia (37°50'S, 140°46'E) is known for its seasonal change of colour: grey during winter, a luminous blue during summer. The transition from grey to blue about November each year occurs quite suddenly, compared to the gradual reversal to grey from mid-summer until April. Several theories, including inorganic precipitation of calcium carbonate and a redox reaction of a plant dye, have been suggested to account for the blue colour, but lack of experimental evidence throws some doubt upon the validity of any of these theories. The present paper reports the preliminary results of an investigation prompted by the lack of such evidence.

The hydrogeology of the region around Mount Gambier was described by Fenner (1921) and Ward (1941). Limited chemical information on the Blue Lake was also published by Bayly and Williams (1964). The limnology of this minute caldera is virtually unknown. In order to study some of the important aspects, the author visited the Blue Lake in September and November of 1967, and again in January and July of 1968.

PHYSICAL LIMNOLOGY

a. *Earlier Studies*

Fenner (1921) and Ward (1941) pointed out that the Blue Lake was recharged via a direct contact with groundwater in the Tertiary and Pleistocene rocks and that there was a high degree of correlation between the cumulative rainfall and the lake level. Beaney (1957) brought the results up to date with a correlation coefficient of 0.85. The results of Bayly and Williams (1964) are informative, yet insufficient, to describe the seasonal regime in the lake. These

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authors expressed similar views with regard to direct contact with the ground-water, and reported that the annual marine atmospheric cycle largely determined the relative ionic proportions of salts in the lake. As a result, the lake waters on analysis rendered a relatively different composition to the surrounding ground-water.

Periodical analysis of lake water for the variation of tritium content may provide a basis to verify a number of critical facts as regards the source of recharge water and its movement in time and space.

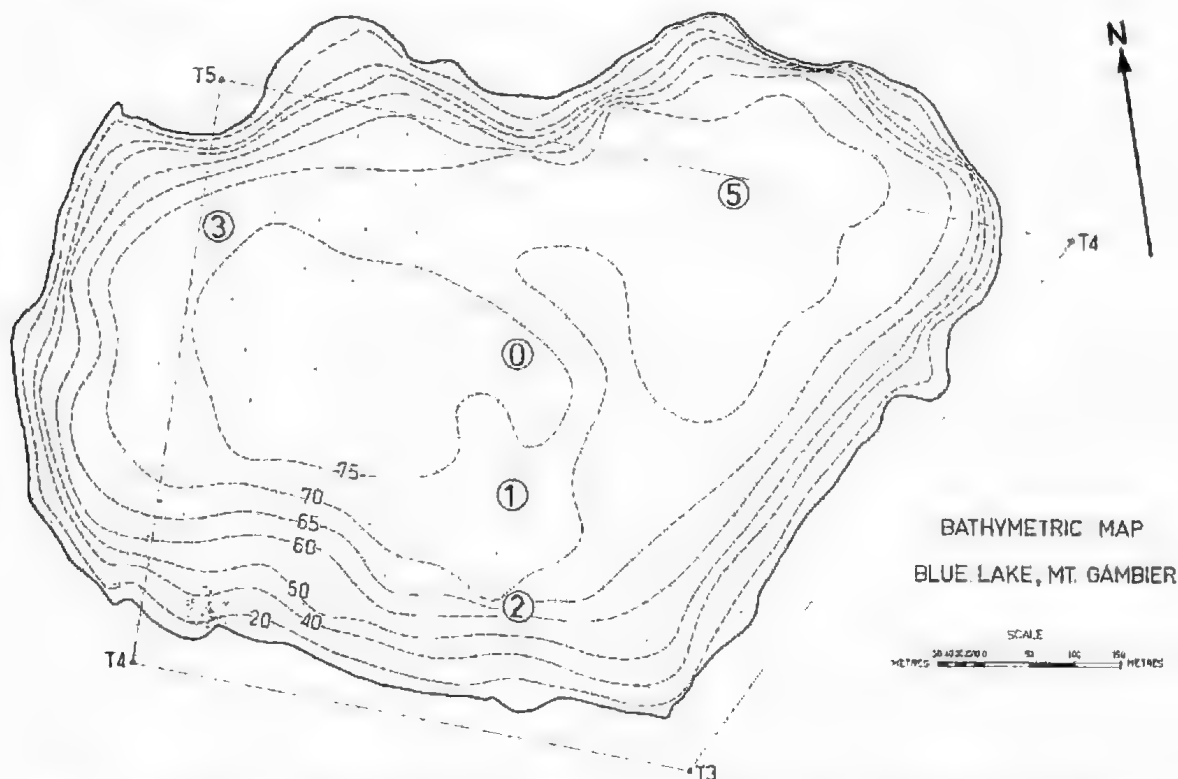


Fig. 1. Bathymetric map of the Blue Lake, with location of temperature and water sampling stations. Depths in metres. This map was originally constructed by the Department of Interior.

b. Morphometry

The morphometric data were calculated according to the procedure given by Hutchinson (1957) from a bathymetric map of the Blue Lake (Fig. 1). This was constructed by the Department of Interior in collaboration with the Horace Lamb Centre of the Flinders University of South Australia. Soundings were taken about 50 m apart, from which contours were drawn at 10 m intervals to a depth of 60 m, then at 5 m intervals to the bottom. For the purpose of calculation, the area at the maximum depth of 77 m was considered as zero.

Morphometric terms (following Hutchinson, 1957)

- A_z = area at each contour in m^2 , by planimetry,
- A_m = mean area between two successive contours in m^2 ,
- V_z = volume between two successive contours in m^3 ,

- VP_z = progressive volume between two successive contours in m^3 , by summing up the V_z terms,
 Z = depth in m,
 Z_m = maximum depth in m,
 \bar{Z} = mean depth in m,
 Z_c = depth of the deepest point in the lake below sea level in m,
 D_v = development of volume, ratio of the mean to the maximum depth.

Results

The principal morphometric features of the lake are set out in Table 1.

TABLE 1

Z	$A_s \cdot 10^3$	$A_m \cdot 10^3$	$V_z \cdot 10^3$	$VP_z \cdot 10^3$
0	603			
10	588	596	5,960	36,760
20	567	578	5,780	30,800
30	544	556	5,560	25,020
40	517	530	5,300	19,460
50	482	500	5,000	14,160
60	431	457	4,570	9,160
65	378	404	2,020	4,590
70	270	324	1,620	2,570
75	79	175	875	954
77	0	39	79	79
Z_m	\bar{Z}	Z_c	D_v	
77	61	61.6	0.79	

The area of the lake at water level is 0.603 Km^2 (149 acres) and its volumetric capacity, $36.8 \times 10^6 \text{ m}^3$ (8090×10^6 gallons; cf. Ward, 1941; 170 acres, and 8000×10^6 gallons).

c. Temperature

Measurement and results

Measurements were taken at 5 stations (Fig. 1). The stations 0 and 5 were worked at more regular intervals than stations 1, 2 and 3. Vertical temperatures in situ were obtained from the readings of a Negretti and Zambra protected reversing thermometer. Overnight temperatures were not recorded. The results in this study (Fig. 2) are, however, considered to represent typical averages over a 24-hour period. Fig. 3 was constructed by interpolation to show the monthly variation of surface water temperatures T_w . The air temperatures, T_a for the same period are also included in the figure.

Discussion

As shown in Fig. 2, thermal stratification begins after September, becomes prominent in November and increases further in January. Until September, the lake is isothermal. It may be seen from Fig. 3 that the surface water temperature has a maximum in February, when the stratification probably is strongest.

The maximum temperature gradient in January occurs between 15 and 35 m depth. The rate of fall in temperature is 0.24°C per metre, far less than Birge's

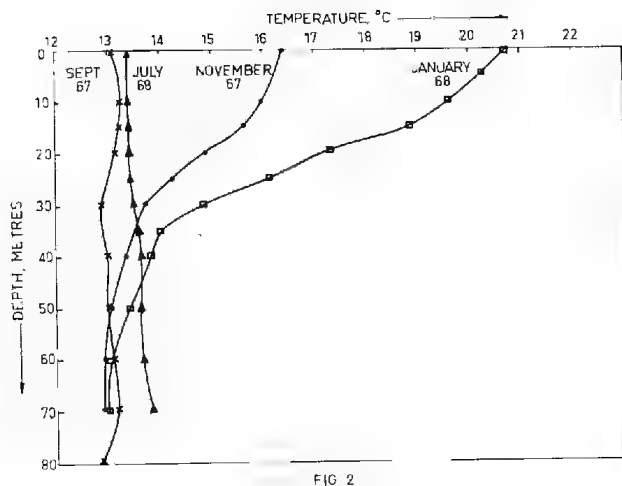


Fig. 2. The variation of temperature with depth of the Blue Lake.

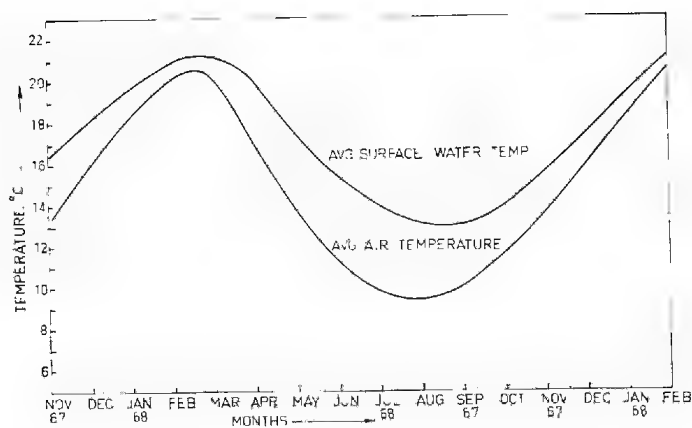


Fig. 3. The seasonal variation of surface temperature of the Blue Lake and mean air temperature.

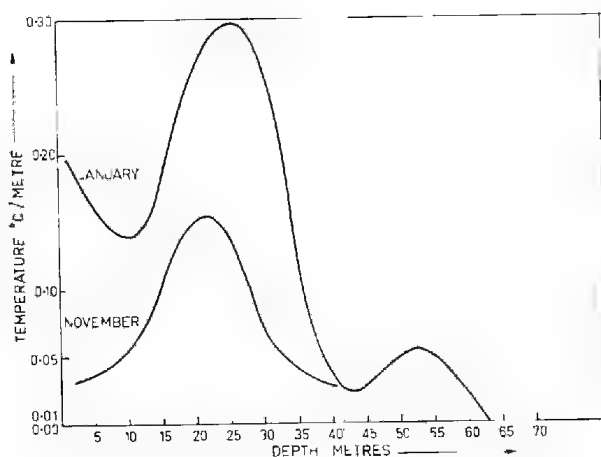


Fig. 4. The rate of change of temperature as a function of depth in the Blue Lake.

(1897) defined gradient of $\geq 1^\circ\text{C}$ per metre for a thermocline. Such a gentle thermal gradient may be the result of the large D_v , 0.79 in the Blue Lake.

According to the Brönsted and Wesenberg-Lund (1911) concept, the plane of the thermocline lies at 20-25 m in November and shifts to 25-30 m in January (Fig. 4). The temperature falls at the rate of 0.16°C and 0.30°C per metre, respectively.

Ertel (1954) proposed that the inflexion point of the thermal curve is displaced to a greater depth in the course of the heating period. This implies that the observed inflexion point at 20 m in November (Fig. 2) would be displaced to

$$\text{a depth of } 20 \times \sqrt{\frac{131}{61}} \cong 29 \text{ metres}$$

in January which, in fact, is comparable with the depth of the plane of the thermocline at 25-30 m (Fig. 4). The numbers 61 and 131 correspond to the elapsed time in days between 15th September, when the lake was isothermal, and 15th November and 25th January, respectively.

d. Energy-Budget

Methods and related data

The characteristic heat-terms (Welch, 1952) for the lake, which enter the following equation (Hutchinson, 1957) were computed from the present series of observed data and from some earlier radiation measurements:

$$Q_r \pm Q_v = Q_e + Q_b \pm Q_t \quad \dots (2.1)$$

Recorded data obtained from a Funk-type (1959) net radiometer exposed over grassland near Mount Gambier (C.S.I.R.O., Div. Soils, Adelaide, data for 1963-5) were corrected to the differences of temperature and albedo between lake and atmosphere to obtain net radiation, Q_r , above the lake surface. Q_b , the change in the potential (stored) heat was estimated from the data in Table 1 and Fig. 2. Evaporation E was calculated from the Dalton-type equation (Sverdrup, 1937, 1951)

$$E = 0.0024 (e_w - e_a) V \quad \dots (2.2)$$

and was then converted to Q_v , the evaporative heat in the lake. e_w and e_a are vapour pressures at the surface water temperature T_w and air temperature T_a , respectively (Fig. 3). V stands for the wind speed, while the bulk aerodynamic coefficient, 0.0024, was that obtained from a number of extensive studies on evaporation in lakes (Anderson et al., 1950; Budyko et al., 1954; U.S. Geological Survey, 1954a, 1958; Bruce and Rodgers, 1959; Webb, 1960).

The quantity Q_h or the sensible heat was obtained from the product of Q_r and the Bowen ratio, β (Bowen, 1926):

$$Q_h = \beta \cdot Q_r \quad \dots (2.3)$$

Individual values of β for each month were calculated using the surface water temperature T_w , air temperature T_a (Fig. 3), and e_w and e_a at these temperatures. The barometric pressure, P , at Mount Gambier, was assumed to remain at 1000 mb throughout the year. The following equation was used to calculate β (Sutton, 1953):

$$\beta = 0.61 \left| \frac{T_w - T_a}{e_w - e_a} \right| \frac{P}{1000} \quad \dots (2.4)$$

The advective heat, Q_v , was found by difference from (2.1).

Local meteorological data were substituted for the quantities T_a (e_a) and V in Equations (2.4) and (2.2).

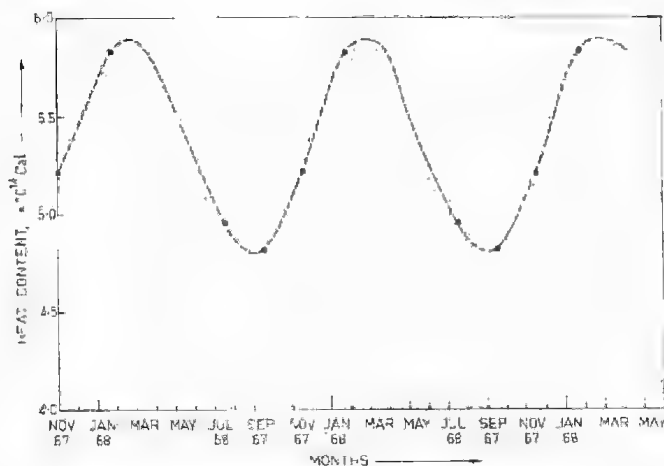


Fig. 5. Heat content of the Blue Lake.

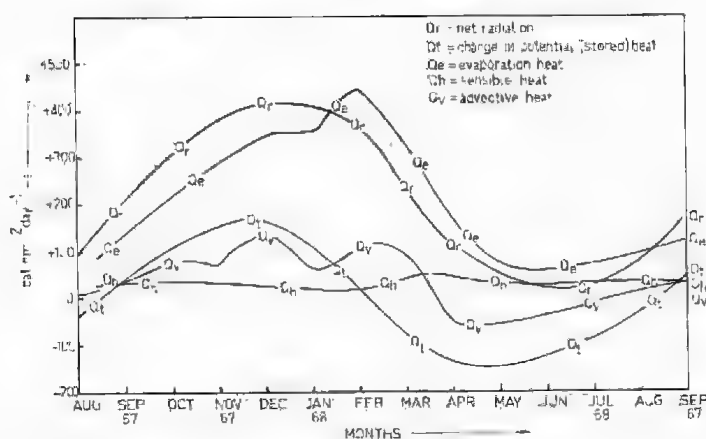


Fig. 6. The components of the energy budget of the Blue Lake.

Results and discussion

Monthly values of Q_t in the lake were read from Fig. 5 which shows the total stored heat for the experimental period of 12 months. The energy-budget is graphically presented in Fig. 6.

The calculations provide a model energy-budget which is likely to be improved later with additional observational data. A radiation map of the lake would be useful if these studies are to be refined. Use of the empirical coefficient 0.0024 in (2.2) is an assumption yet to be tested by experiment. It is found that the estimate of the lake evaporation E by equation (2.2) closely agrees with that computed from Class "A" evaporimeter pan results for Mount Gambier (Bureau of Meteorology Bulletin 44, 1961); for a period of 9 months (data available for Class "A" pan), these are 1225 mm and 1166 mm respectively.

The advective component in Fig. 6 is significantly large at least for the summer months. A Q_v of $150 \text{ cal. cm}^{-2} \text{ day}^{-1}$ amounts to an equivalent underground discharge of nearly 0.82 million m^3 of water per day, if the inflow is to change the lake temperature by 1°C ; for a change of 2°C , the inflow would be 0.41 million m^3 a day. An advected subterranean flow at this rate may persist in the Blue Lake. It is reported (Ward, 1941) that a large outflow of freshwater to the sea of the order of 0.32-0.38 million m^3 a day occurs from the nearby springs at Ewen Ponds.

e. Light Penetration

A Secchi disk of 30 cm diameter and twice coated with a flat white paint was used to study the transparency of the lake water. The mean of the depths of disappearance and reappearance of the disk observed under a shade was recorded as the depth of visibility, D . The extinction characteristics were then found from an empirical approximation (Poole and Atkins, 1929), by which the extinction coefficient k is defined by

$$k = \frac{1.7}{D} \quad \dots (2.5)$$

Lambert-Beer's law $\frac{I}{I_0} = e^{-kdc}$ \dots (2.6)

where I = observed light intensity at depth d , and I_0 = incident light intensity, relates k to the concentration c of any material that produces turbidity in the medium and, therefore, regulates the depth of visibility D . A derived form of Equation (2.6) $k = \frac{(4.6/d') - 0.03}{c}$ \dots (2.7)

is used to determine c (Verduin, 1959). In general, d' , the depth of 1% surface light or the limit of the euphotic depth, is taken as equal to 3-4 times the Secchi disk transparency D (Riley, 1965). A comparable, but more precise value of d' is derived from the Lambert law $I_z = I_0 e^{-kz}$, where z is the depth and k the extinction coefficient. The value of d' can also be determined by measuring 1% surface light with a submarine photometer. The value of 0.03 in the above equation is introduced to account for the extinction by pure water alone.

Light observations with a Secchi disk provided useful information with regard to the optical properties of the lake water. The seasonal variation of the depth of visibility D , and hence that of the extinction coefficient k , indicated that an influx of additional material to the lake occurred just at the onset of summer. The measurements of the two quantities given in Table 2 imply nearly a 50% reduction of D , increasing k from a value of 0.1133 to 0.2125 immediately after the blue coloration around mid-November. Later measurements tend to confirm that D increased gradually in keeping with the lake becoming progressively grey following the approach of autumn and winter.

TABLE 2
Optical properties and suspensoids and dissolved material

Time	Colour	D	k	c
Sept. 1967	Grey	14.5m	0.1133	0.68 p.p.m.
Nov. 1967	Blue	8.0m	0.2125	0.80 p.p.m.
Jan. 1968	Blue	12.5m	—	—
July 1968	Grey	14.0m	—	—

D , depth of visibility k , extinction coefficient c , suspensoids and dissolved material

The extinction coefficient k determines the amount of light absorbed and scattered by water (k for pure water = 0.035) and by matter present in water; thus a k of 0.1133 in September implies an attenuation of the incident sunlight by about 31% by water and 69% by matter held in water; in November, for a k of 0.2125, the attenuation is altered to 16.5% and 83.5%, respectively.

CHEMICAL LIMNOLOGY

A number of chemical and related parameters were investigated both in the field and by bench analysis of water samples. The samples (1-2 litres) were collected in black, high density polyethylene containers. Certain interacting characteristics are discussed together, with a view to understanding the lake's chemistry in terms of simple equilibria.

*Methods**a. Dissolved oxygen*

Water samples collected by a Nansen bottle were analysed in the field polarographically by a WPRL Dissolved Oxygen Meter A1672, using a wide-bore dropping mercury electrode in conjunction with an Ag-AgCl standard (Briggs and Knowles, 1958, 1961). The method has a standard deviation of 0.06 p.p.m., and the determinations at the sample pH are virtually free from chemical interferences of a large number of cations and anions usually present in lake waters.

The percent saturation of oxygen was calculated from the generally accepted formula,

$$\% (O_2)_{\text{sat}} = 100 (O_2) / (O_2)_{\text{sat}} \quad , \quad \dots (3.1)$$

where (O_2) = measured oxygen concentration, and $(O_2)_{\text{sat}}$ = equilibrium oxygen concentration.

The oxygen consumption in the lake waters was expressed in terms of Redfield's (1942) apparent oxygen utilisation (A.O.U.) given by

$$\text{A.O.U.} = (O_2)_{\text{sat}} - (O_2) \quad \dots (3.2)$$

The measured oxygen concentration (O_2) was read directly off the Dissolved Oxygen Meter in p.p.m. Published tables (Montgomery et al., 1964) were consulted to obtain $(O_2)_{\text{sat}}$ at the relevant temperature of water and 1013 mb pressure. A few oxygen measurements may have involved an element of error (10%) due to instrumental malfunction.

b. Colloidal matter

The technique of Tyndall scattering was applied to the detection of substances present in the colloidal state. The intensity of light scattered from filtered samples (double Whatman No. 42) was measured in the laboratory in the arbitrary scale of a galvanometer; in this way, waters of different origin were compared with regard to the relative presence of scattering matter.

The light scattering measurements were made with an EEL Nephelometer in which a 12v-48w globe was used as a source of incident white light. The angular distribution of the scattered light at $< 45^\circ$, $< 90^\circ$ and $< 135^\circ$ to an incident monochromatic beam (Hg-vapour lamp, $\lambda = 5460 \text{ \AA}$) was examined further, from another set of measurements on water samples with a Sofica Photo-Conio Diffusometer.

c. pH

A battery-operated Coleman pH-meter Model 37A was used in conjunction with a Tri-purpose combination electrode for the determination of pH. Samples were analysed soon after collection and at ambient room temperature. A week's collection of surface waters preceding 15th November, 1967 were also tested in order to follow closely the pH regime and its variation during the final stages of the lake's transition from grey to a blue colour.

d. Major and minor elements

Total solids were obtained by weighing dry matter left from evaporating aliquots of water samples (300 ml) in platinum dishes. A qualitative elemental survey of the lake water was made by emission spectrographic method of analysis in which a compact mixture of equal parts of the dry residue and graphite powder was burned as anode by D.C. arc excitation. The spectrographic plate was then compared with a standard plate containing the spectral lines of the respective elements under consideration.

Among the major cations in the lake water, only calcium was determined by flame photometry (EEL) of the lake water acidified to a pH of about 6. A small number of samples were analysed for traces of copper, cobalt and nickel by a combined technique of chelation (0.5% Na-diethyldithiocarbamate), solvent extraction (Methylisobutylketone, volume reduction 20X) and atomic absorption spectrophotometry.

e. Dissolved organic matter

Soluble organic matter of indeterminate composition occurs in all natural waters. These substances usually result from degradation of particulate organic matter, and also as metabolites and faecal products of living organisms. One specific class of organic compounds is known to exist in a chemically stable form as fluorescing substances in solution. The chemical route of formation of these substances is still obscure, although their presence in natural waters has been reported by several workers (Merker, 1931; Kalle, 1938, 1939, 1949, 1962; Hutchinson, 1957; Welch, 1952; Duursma, 1965).

The development of effective analytical techniques (extraction; chromatography) to isolate these substances non-destructively and to identify them remains as problematic as ever. The fluorescence characteristics, in particular, may be used to reveal at least in a qualitative manner the existence of organic matter in one form or another. With this assumption in view, initially an ultraviolet absorption spectrum (2000Å-3000Å) of the lake water was obtained on a Perkin-Elmer SP 800 spectrophotometer. Rather symptomatic information was gathered on a relative scale by analysing filtered waters with an "Eppendorf" Photometer for fluorescence characteristics at the selected wavelengths of 3020Å-3660Å, 4050Å-4360Å and 5460Å, respectively.

TABLE 3
Total solids in p.p.m.

Depth, m.	September	October	November
0	378	390	372
10	—	—	374
15	380	—	371
20	—	—	369
50	378	—	379
Ward (1941)	May	June	December
Surface	413	394	360

Results and discussion

The seasonal increment of c (cf. Table 2) by about 0.1 p.p.m. appears to be due rather to soluble than solid matter of super-colloidal dimension ($\geq 10^4 \text{ \AA}$). The total solids in the lake water were found to be systematically less during the summer season; the results in Table 3 agree with those given by Ward (1941).

The present series of nephelometric measurements (EEL) hardly suggest a periodical increase of colloidal matter (size: 10^4 \AA to 10^6 \AA) which may diffract sunlight and produce a blue colour in the lake water. The results, plotted in Fig. 7, include measurements from Stations 0 and 5 in September and November.

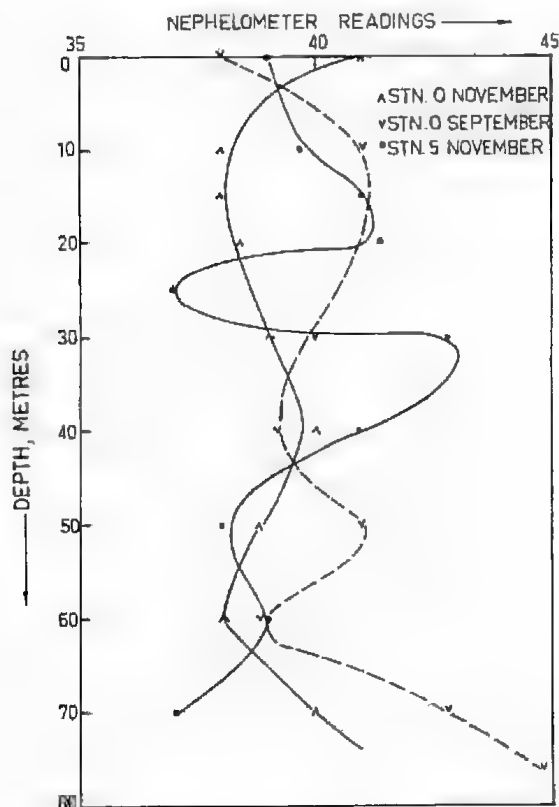


Fig. 7. Light scattering of water samples as a function of depth of the Blue Lake,

The ratio of the scattering of light at $< 45^\circ$ and $< 135^\circ$ is a good measure of the size of macromolecules or polymers in solution (Debye, 1944). The method is very sensitive to sols containing molecules approaching the dimension of the wavelength of the light used, i.e., for molecular weights of $\approx 10^6$ or more. For molecules larger in length than $\lambda/20$, (λ = wavelength of the light), the angular scattering distribution becomes asymmetrical and, as a result, the ratio of $I < 45^\circ / I < 135^\circ$ increases proportionally. The Sofica analysis of the lake water is presented in Table 4 relating the angular ratio with depth.

The results on light scattering indicate both the presence of large molecules in solution and their concentration fluctuations in time and space. It is interesting to note that a large scattering ratio characterises the November samples from depths of 50 m and 15-20 m at Stations 5 and 0, respectively; a point-to-point

TABLE 4
Angular Light Scattering

$I < 45^\circ / I < 135^\circ$			
Stations	0		5
Depth, m.	September	November	November
0	8.0	9.3	7.6
10	12.5	6.0	7.2
15	—	40.5	6.9
20	—	50.0	6.0
25	—	—	10.0
30	4.4	5.8	10.5
40	6.8	9.0	10.0
50	10.5	8.3	35.6
60	7.6	8.7	9.7
70	8.2	10.5	10.7

displacement of characteristic sols could have been induced by subsurface circulation beginning with a large advected flow into the lake in early summer. It is evident that only intensive sampling can assess finally the presence and distribution of macromolecular sols in the lake water.

A transitional low pH typified the surface waters between September and November. The weekly pH dropped from 8.45 on September 1st and fluctuated by about ± 0.55 -0.30 units until the waters attained an equilibrium pH of 8.15 by mid-November (Fig. 8). It is possible that perhaps the lowering and variation of the pH were caused by a variable discharge of underground water during the 6-8 weeks preceding complete equilibration in November. The surface values compare remarkably well with Ward's (1941) measurements in summer and winter, viz. 8.15 and 8.45 to Ward's 8.1 and 8.58. The pH decreases towards the bottom which constitutes a common feature in all lakes. As to the source of

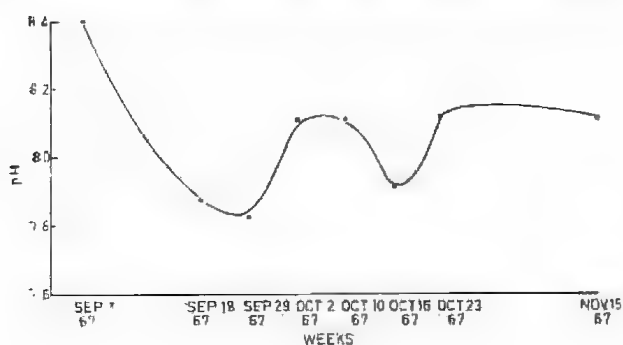


Fig. 8. pH of the Blue Lake water.

acidity of the bottom waters, a chemical analysis of the lake sediments may reveal the identity of the proton-donor. Lack of titration alkalinity data at present precludes a convincing explanation to the lowering of pH during summer; as suggested earlier, an incursion of relatively acidic groundwater may have altered the overall hydrogen ion concentration in the lake water completely. The water samples were examined, in the first instance, by arc-emission spectography. However nothing significant could be detected in terms of differences in concentration between the various elements present in the September (grey) and November (blue) samples.

Inorganic analyses are routinely undertaken by the Engineering and Water Supply Department at Mount Gambier to ensure potability of lake water for local consumption. An official statement of an average inorganic analysis is reproduced in Table 5. It is also of interest to note that a consistent record of negative bacterial counts confirms the absence of significant bacterial growth throughout the year.

TABLE 5
Inorganic analysis of Blue Lake water
(from E. & W.S. Dept. records)

CaCO_3 (present as HCO_3^-)	98 p.p.m.
MgCO_3 (present as HCO_3^-)	66 p.p.m.
MgSO_4	16 p.p.m.
$\text{NaCl} + \text{KCl}$	164 p.p.m.
Miscellaneous salts	12 p.p.m.
Total	356 p.p.m.

The calcium content was found to vary between 30-34 p.p.m. (cf. Ward, 1941; Bayly and Williams, 1964) and the maximum centred around 50 m depth. The lake therefore appears to retain an equilibrium concentration (saturation) at all depths and irrespective of the time of the year. The temporary hardness due to carbonate species remained unchanged both in summer and winter (Ward, 1941). At an atmospheric CO_2 -content of 0.044% by volume at sea level, an equilibrium concentration of 30 p.p.m. Ca^{++} and 90 p.p.m. HCO_3^- can exist in solution in water. Simple equilibria of the CO_2 -system in water (Buch, 1930) and the solubility data of CaCO_3 reveal that the ionic product $[\text{Ca}^{++}] [\text{CO}_3^{--}] = 10^{-8.40}$ for a $[\text{Ca}^{++}] = 30$ p.p.m. and $[\text{HCO}_3^- + \text{CO}_3^{--}] = 3.21$ mequiv/l (Bayly and Williams, 1964) in the lake water is about one tenth of the solubility product of CaCO_3 (calcite), $10^{-8.35}$, at an average temperature of 15-20°C and 8.2 pH. This fact alone excludes the probability of CaCO_3 precipitation under the lake's pH and temperature conditions in the summer season (November to January observations). Chemical precipitation of CaCO_3 can occur only if the pH is to exceed a value of 9. Colloidal CaCO_3 probably exists in the supersaturated hard-water lakes of northern Germany (Ohle, 1934). There was no such observation of calcium or bicarbonate supersaturation in the Blue Lake's waters.

Unlike cobalt, microgram quantities of copper and nickel present in the lake water varied in concentration from September to November. Half of the copper was not available in November, likewise nickel was reduced. This reduction was caused not by fresh-water dilution, because neither a gain nor a loss in concentration was recorded for cobalt. Copper and nickel probably remained strongly bound to active organic solubles (Price, 1967) in the water and were not entirely

stripped by the analytical method of artificial chelation. Such natural complexing agents in solution may resemble humic substances and its fractions in composition. These substances may have their origin in the lake sediments (Kazakov, 1950; Krauskopf, 1956; Romankevitch, 1957; Degens et al., 1964; Palacas et al., 1966) or were carried to the lake by groundwater.

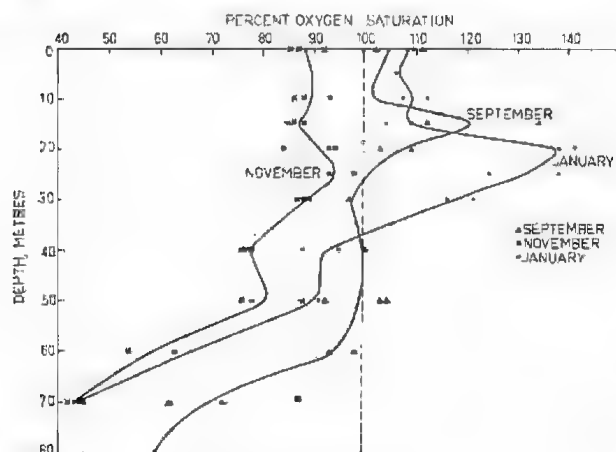


Fig. 9. Oxygen content of the Blue Lake water as a function of depth.

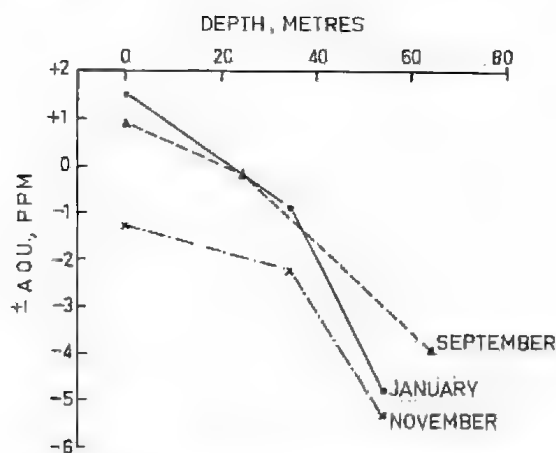


Fig. 10. Apparent oxygen utilization as a function of depth of the Blue Lake.

Some specific points from the results on percent oxygen saturation and the apparent oxygen utilisation are discussed here (Figs. 9, 10). It was observed that the change of the water colour in November coincided with an appreciable oxygen-deficit throughout the water column, and quite markedly so below the 50 m depth. The metalimnetic oxygen maximum at 20 m amounting to 140% supersaturation in the month of January could not have resulted from an outburst in primary production (photosynthesis), because in fact a lower pH (8.15) and a greater depth of visibility (13 m) were recorded in the lake water. According to the photosynthetic reaction:

Photosynthetic reaction

$$n\text{Ca}^{++} + n\text{HCO}_3^- \rightleftharpoons n\text{CaCO}_3 + \overbrace{n\text{CO}_2 + n\text{H}_2\text{O}}^{\text{hv}} \rightleftharpoons n\text{CaCO}_3 + \text{C}_n\text{H}_{2n}\text{O}_n + n\text{O}_2$$

the oxygen supersaturation was also not accompanied by a loss of calcium by carbonate precipitation. The systematic increase of oxygen up to 20 m (Fig. 9),

followed by a rapid decrease in the metalimnion (Fig. 10), was probably induced jointly by the effect of turbulence and chemical oxidation of soluble matter during the summer stratification. By January, therefore, the oxygen profile assumed a typical form of a positive heterograde distribution (Hutchinson, 1957).

The U.V. absorption spectrum of the lake water rendered little information. The photometric analyses on the "Eppendorf" were quite instructive about the existence of fluorescing matter. The measurements were taken against a fluorescent standard cuvette and using a primary filter to isolate the selected wavelengths in conjunction with a secondary filter to prevent the unwanted scattered light from reaching the photomultiplier. Fluorescence from the samples was strongest at the 3020Å-3660Å waveband, but gave a greatly reduced signal at 4050Å-4350Å and was practically negligible at 5460Å. The relative intensities at 3020Å-3660Å were averaged for each depth and are plotted in Fig. 11.

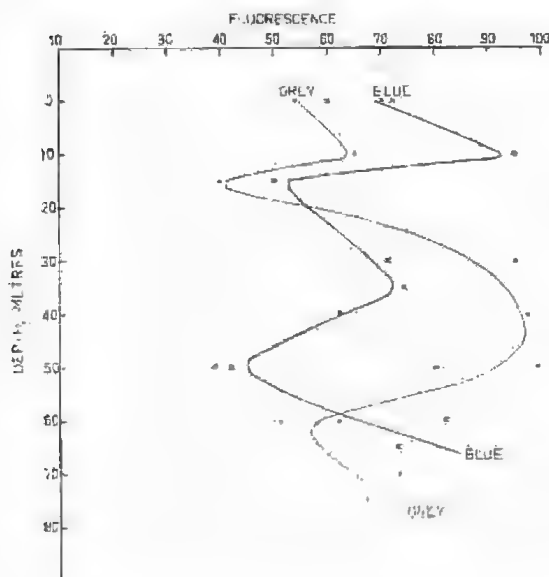


Fig. 11. Relative fluorescence of water samples as a function of depth of the Blue Lake.

The standard cuvette was used as a control for instrumental drift. There are at present a number of basic difficulties in the calibration procedure. The fluorescing matter therefore could not be assessed in terms of concentration.

The chemical synthesis of the humus-like fluorescing matter in the natural environment was investigated by Enders (1943) in great detail. Long ago, Kalle (1938-39) suggested that such fluorescing matter appeared to be one of the decisive components in producing a blue colour in the ocean. These substances were known to fluoresce light blue in the U.V. light, and were said to form, by a different route of condensation of methylglyoxal, the initial breakdown product of a carbohydrate (Enders, 1943; Kalle, 1962).

The light sensitive matter in the lake water may resemble these substances in solution which would strongly chelate the number of transition elements; as they are also weakly acidic they would slightly, but effectively, increase the hydrogen-ion concentration and undergo photooxidation and photoexcitation in the presence of oxygen and solar radiation with ten times more ultraviolet in the summer season. Ward (1941) reported in his article that, in fact, the lake water

absorbed four times more oxygen in summer when subjected to a 4-hour permanganate oxidation at room temperature.

A blue fluorescence results from excitation at 3020Å-3660Å; the lake water was excited most at this bandwidth. The blue coloration appears to be more luminous than dull. Large masking particles are virtually absent in the lake water; the fluorescent blue, therefore, is more prominent than any other colour.

Fluorescing matter may be brought to the lake in solution by groundwater, or released chemically at the lake mud-water interface (Mortimer, 1941-42). Chemical stratification of these substances seems to occur in the Blue Lake throughout the year (Fig. 11). The physico-chemical history of the lake changes quite considerably with a large inflow after September each year. The buildup of the soluble organic matter then reaches a threshold concentration in the epilimnion, after which the blueness in the lake becomes fully perceptible.

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THE STRATIGRAPHIC DISTRIBUTION OF THE EDIACARA FAUNA IN AUSTRALIA

BY MARY WADE*

Summary

The uppermost Precambrian Ediacara fauna has been found in almost continuous outcrops along the west flank of the Flinders Ranges, from near Hawker to Mt. Scott Range 140 km north. All occurrences are stratigraphically low in the upper member of the Pound Quartzite. In parts of this region erosion prior to deposition of the Parachilna Formation has removed 500 m or more of the upper member; the entire upper member was eroded prior to the deposition of the Parachilna Formation or the Lower Cambrian Wilkawillina Limestone, in the ranges on the east flank. Trace fossils, *Plagiogmus* and probable *Rusophycus*, indicate a lowest Cambrian age for the Parachilna Formation, which is overlain by the Wilkawillina Limestone or its equivalent the Ajax Limestone.

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ABSTRACT

The uppermost Precambrian Ediacara fauna has been found in almost continuous outcrops along the west flank of the Flinders Ranges, from near Hawker to Mt. Scott Range 140 km north. All occurrences are stratigraphically low in the upper member of the Pound Quartzite. In parts of this region erosion prior to deposition of the Parachilna Formation has removed 500 m or more of the upper member; the entire upper member was eroded prior to the deposition of the Parachilna Formation or the Lower Cambrian Wilkawillina Limestone, in the ranges on the east flank. Trace fossils, *Platygmus* and probable *Rusophycus*, indicate a lowest Cambrian age for the Parachilna Formation which is overlain by the Wilkawillina Limestone or its equivalent the Ajax Limestone.

INTRODUCTION

The rich Precambrian fauna discovered near the top of the Pound Quartzite at Ediacara Range by Sprigg (1947, 1949) was augmented by the collections of Mincham and Flounders (Glaessner, 1955 *et seq.*) and later workers. These discoveries and the failure to find fossils at other levels in the Precambrian at Ediacara triggered fruitless searches concentrated on the top of this formation elsewhere. Only in the area of outcrop closest to Ediacara Range, Red Range, Beltana, was a small fossiliferous outcrop revealed; this was 180 m below the top of the Pound Quartzite, a much greater distance than at Ediacara, and in a much thicker sequence. The stratigraphic relationships of these two isolated areas remained uncertain.

The study of the preservation of the soft bodied fauna (Wade, 1968) brought out the fact that requirements for preservation were not particularly stringent. The fauna could be preserved anywhere that sediments which had finally been deposited without reworking could be found. Such an environment was ascribed to the Ediacara Range deposit on independent sedimentary evidence by Goldring and Curnow (1967). The conditions required for the exposure of fossils were either that the rocks were naturally flaggy, or that the fossils were sufficiently tough and large to cause a weakness in a massive rock where sand-grains had been prevented from interlocking, so that the rock parted along the site of the fossil during weathering. Accordingly a new investigation was launched, which concentrated on finding suitable beds. It was immediately successful.

The present paper records the stratigraphic position and distribution of the Ediacara fauna within the area shown in Fig. 2. Fig. 2 shows the outcrop of the Pound Quartzite in the area outlined in Fig. 1 and indicates the 22 sections examined in the course of this work. Areas not yet examined include the thickest development of the Pound Quartzite, the northeast of the Northern Flinders Ranges.

PREVIOUS WORK

Reference to the Pound Quartzite is found in many of the works of Mawson who measured sections at Italowie Gorge and Campbell's Bald Hill Range (Mawson, 1937), defined the formation (Mawson, 1938), gave the earliest description of the two members into which the formation is still informally divided (Mawson, 1941), and preliminarily mapped most of the Central Flinders Ranges

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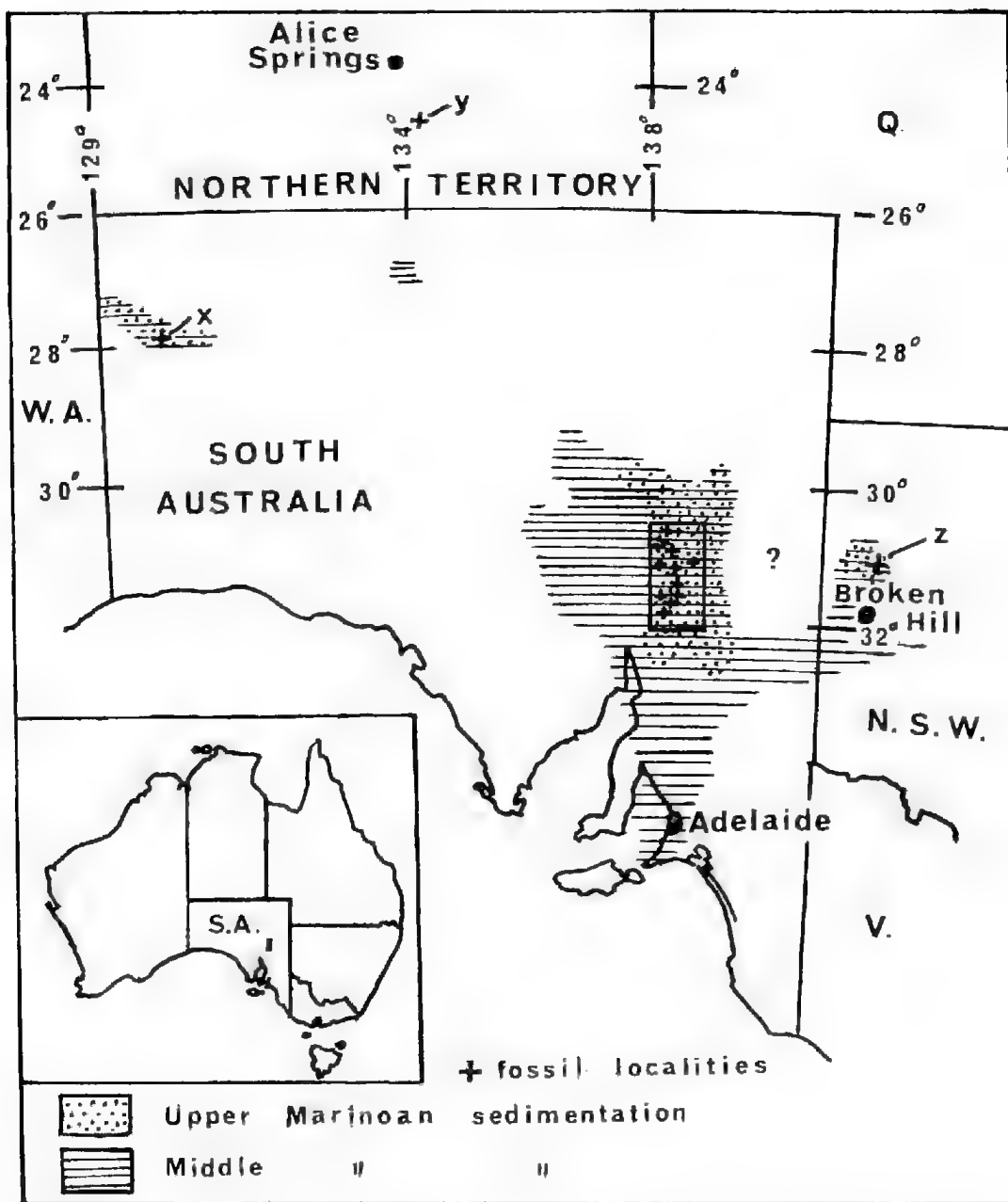


Fig. 1. Areas of Late Precambrian sedimentation showing localities where fossils of the Ediacara fauna have been discovered. Boxed area, within the Flinders Ranges, see Fig. 2; "x" Punkerri Hills; "y" a few km E of Deep Well Homestead SSE of Alice Springs; "z" Fowlers Gap Beds underlying Lintiss Vale Beds a few km NW of Acacia Downs Homestead, NNE of Broken Hill. (Mainly after Thomson, 1969a, and Webby, 1970.)

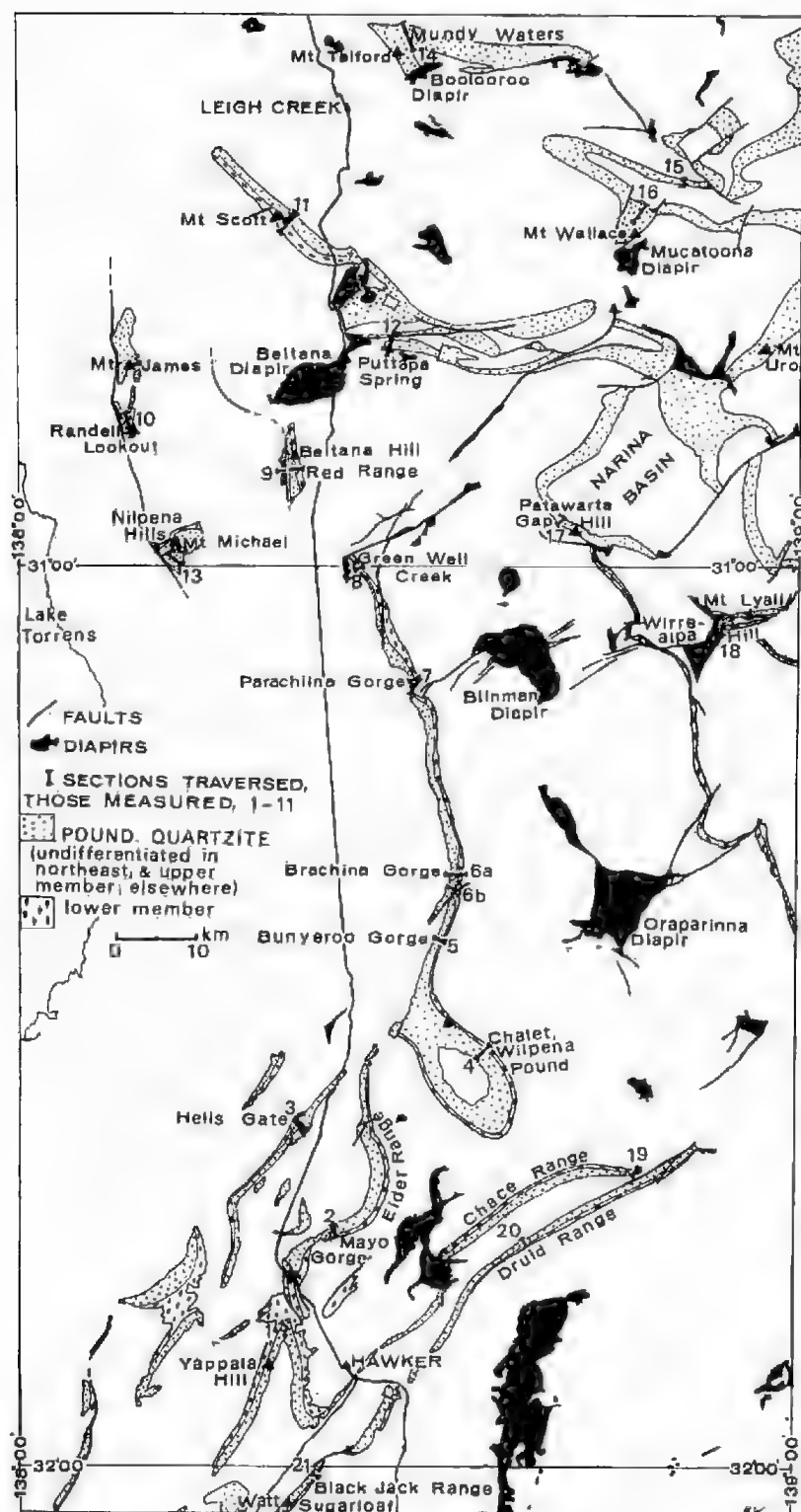


Fig. 2. Outcrop of Pound Quartzite showing sections searched for fossils: fossils *in situ* have been obtained from 1-3, 5-11; definitely fossiliferous float from 13 and 17, Nilpena Hills and Patawarta Gap, and probably fossiliferous float from Puttapa Spring, 12. Diapirs within the area are shown in black.

(Mawson, 1942). Additional references may be found in Teesdale-Smith (1959). There is considerable difficulty in reconciling some of the thicknesses obtained in this early work with later data. Campana (1958) provided a number of structural sections across the Northern Flinders Ranges but omitted the thicknesses of beds. Thicknesses are provided by Thomson (1969b) in interesting diagrams of the facies relationships but the diagrams are of too small a scale to allow precise geographic location, or to show structure.

Modern stratigraphic work at Ediacara commenced with Glaessner and Daily (1959) and was continued by Nixon (1963), and by Goldring and Curnow (1967) on the sediments. Goldring and Curnow convincingly demonstrated an unconformity between the Pound Quartzite and the overlying Parachilna Formation at Ediacara Range, though their paper was not cited by Leeson (1970) who adhered to the view that there was no significant break and Segnit's report (1939) of a disconformity in this position was wrong. Meanwhile Dalgarno (1962, 1964) and Dalgarno and Johnson (1962, 1964) in defining and discussing the Parachilna Formation in the main Flinders Ranges had already shown a regional unconformity in the same position, which may be equated with that at Ediacara.

The first large-scale attempt to systematize the description and naming of beds in the Adelaide Geosyncline was carried out by Daily (1956) on the Cambrian. Thomson *et al.* (1964) similarly established a regional nomenclature for the Precambrian. The most recent review is that of Thomson (1969b).

Since the 1950's the South Australian Geological Survey has been issuing maps of parts of the relevant area on the 1:63,360 scale. More recently this data and that gathered by later work has been distilled into 3 sheets of the 1:250,000 geologic map series. From S to N these are: Orroroo (Binks *et al.*, 1968), Parachilna (Dalgarno and Johnson, 1966) and Copley. The last is an unpublished preliminary version displayed in MS. The Parachilna 1:250,000 sheet was the first to record the distribution of the lower and upper members of the Pound Quartzite. This example was followed in the 1:63,360 map series but regrettably not in the Orroroo 1:250,000 sheet, nor, as yet, in the Copley sheet. Reports of investigations accompany some map sheets: Arrowie (Horwitz, 1962), Blinman Dome (special series; Coats, 1964a), Marree (Forbes, 1966), Beltana (Leeson, 1970), or concern other projects such as the hydrology of Frome Embayment (Ker, 1966) which assembled little-known subsurface data.

STRATIGRAPHY

The Pound Quartzite is the youngest formation in the Adelaide Geosyncline to which the age "Marinoan" has been applied (Thomson *et al.*, 1964; Thomson, 1969b). If it is intended that Marinoan reach to the base of the Cambrian (Thomson, 1966), however, a subsidiary type area where the rocks do not terminate in an unconformity should be sought.

All beds containing elements of the Ediacara fauna have been placed in the Upper Marinoan Epoch (Fig. 1, +). Within the Adelaide Geosyncline the beds deposited during the Marinoan have already been recognized as susceptible of a 3-fold subdivision (Thomson *et al.*, 1964; Thomson 1969b, pp. 68-79, figs. 22, 27). This subdivision appears likely to be widely applicable. The oldest or Lower Marinoan sediments are influenced by the third and last phase of Precambrian glaciation which has been used for correlation with northwest New South Wales (Webby, 1970), and is possibly correlative to the last phase of glaciation in the East Kimberleys, which is overlain by marine shales currently dated at 665 ± 45 m.y. (Compston and Arriens, 1968). The Lower Marinoan sediments of the Adelaide Geosyncline are part of the Umberatana Group which also includes all

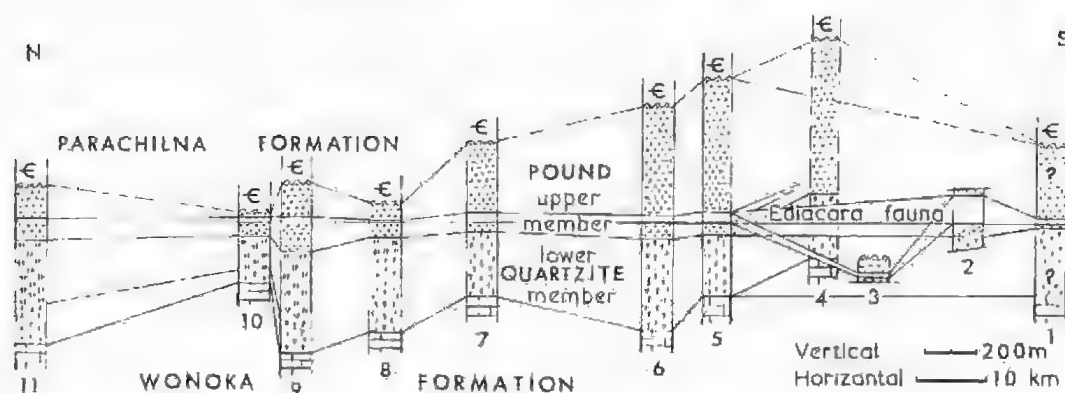


Fig. 3. Sections 1-11 as named on fig. 2. Only the central portion of section 1 was measured, the total thickness is conservative.

the Sturtian glacial and inter-glacial beds. Stromatolites are the only known fossils. The remainder of the Marinoan sediments are the Lower and Upper Wilpena Group sediments (Thomson, 1969b, fig. 27) which may be regarded respectively as Middle and Upper Marinoan. The trace fossil *Bunyerichnus dalgarnoi* Glaessner (1969) was described from the Middle Marinoan of Bunyerroo Gorge but no other fossils are known. The Upper Marinoan consists of the Bunyerroo and Wonoka Formations and the Pound Quartzite which alone has produced animal fossils. These are of such variety and size that a long history of development must lie in older sediments.

Fig. 1 shows the distribution of sediments of Middle and Upper Marinoan age (after Thomson, 1969b, fig. 27; Webby, 1970) and known fossil localities of the Upper Marinoan. The area marked "?" is the Frome Embayment of Mesozoic

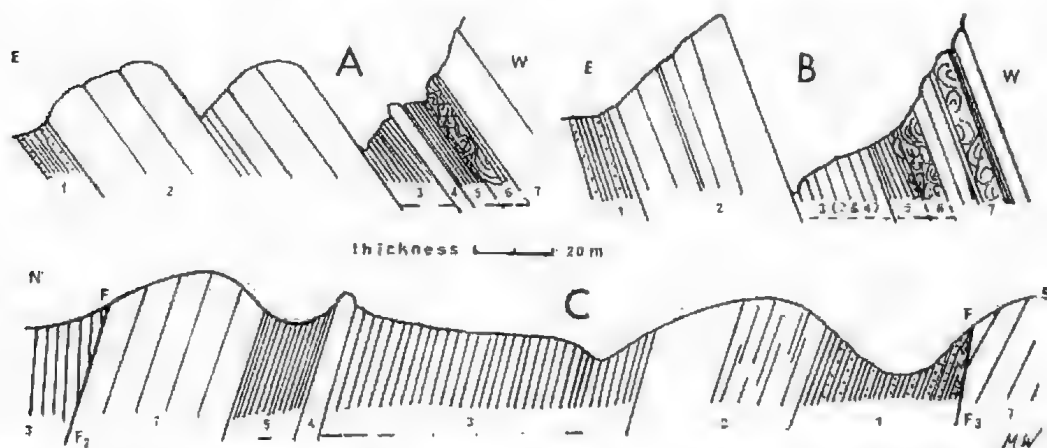


Fig. 4. Generalized sketches of the outcrop from the top of the lower member, Pound Quartzite, through the fossil beds. True dips and thicknesses are shown. A. Brachina Gorge. B. Bunyerroo Gorge. C. Mayo Gorge. 1. Top of lower member. 2. Unfossiliferous basal beds of upper member. 3. Lowest fossiliferous bed. 4. Unfossiliferous intercalation. 5. Upper fine-grained fossiliferous bed. 6. Fossiliferous, fine- to coarse-grained, white sandstones. 7. White sandstones of the cross-stratified to flat stratified facies. Slump rolls have been observed in 5-7 where diagrammatically indicated. The horizontal lines below 3, 5, 6 indicate approximately the position of fossiliferous beds.

to Recent age which is known from bore data (Ker, 1966) to be underlain by Precambrian and Cambrian rocks in N-S trending blocks, like these exposed on its east and west margins. Detail on the correlation of possible Adelaide System rocks is lacking.

The Pound Quartzite

This formation occurs between approximately 30° and 32°33'S latitude. It rims many synclinal and basinal structures in the Northern and Southern Flinders Ranges but is restricted to the flanks of the Central Flinders Ranges (Fig. 2) where uplift and deep erosion has exposed Sturtian rocks and large diapiric cores (Mawson, 1942; Coats, 1964a; Dalgarno and Johnson, 1966). Immediately prior to the deposition of the Pound Quartzite, fine-grained carbonate-rich sediments were deposited over the area. These rocks are known as the Wonoka Formation (Dalgarno and Johnson, 1964) and are usually grey to brown or red siltstones and shales with bands of limestone but occasionally dolomite or limestone predominate.

The base of the lower, or red, member of the Pound Quartzite indicates an abrupt regional change to haematitic, felspathic sandstones (Fig. 3), usually through non-calcareous, red siltstones. The member is dominantly medium- to fine-grained, with ferruginous coatings on the grains in most beds, though some included sandstones are orthoquartzitic; it contains minor amounts of clayey siltstones and a very few grits; small-scale cross-bedding is dominant but current-swept, flat bedding planes also occur; ripple-marks are common; a few bedding planes reveal a suitable lithology for the preservation of fossils but only rarely have possible trails been found. A basal conglomerate occurs south of the Beltana Diapir in Red Range (Leeson, 1970).

The upper, or white, member consists of clean, coarse to medium-grained felspathic sandstones, with rare fine sediments. For the most part beds are rather massive and cross-stratified to flat-stratified (Goldring and Curnow, 1967). Slump rolls are common in some beds, as are mudflake conglomerates, cut-and-fill scours and ripple-marks. Grit bands are rare; conglomerate bands occur adjacent to Mucatoona Diapir. For the most part reworking during deposition has removed any ferruginous coatings from grains but at a height of about 16-80 m above the base in the west flank of the Flinders Ranges, red beds are included in a substantially fine-grained deposit which extends for 145 km N-S, from the south branch of Green Well Creek to Black Jack Range, south of Hawker. A great deal of this is very fine-grained sandstone and minor siltstones and much of it is fossiliferous. The thickness of the fine-grained beds varies from 7-112 m, largely according to how much barren sandstone is interbedded. The barren sandstones may be relatively fine and even-bedded (Mayo Gorge, Bunyeroo Gorge; Figs. 3 (2.5); 4C,B); mud-pellet conglomerate, coarse sandstone, and small "slump rolls" (Brachina Gorge, Figs. 3 (6), 4A); or slump rolls up to 2-3 m thick and normal, bedded sandstones (Parachilna Gorge, Fig. 3 (7)). Evidence of slumping and/or scouring is recurrent wherever sections have been examined.

Fossils are known in almost continuous outcrops from Green Well Creek to Yappala Range just WNW of Hawker. Isolated from these almost continuous outcrops are beds with fossils at Red Range, Edicara Range and Mt. Scott Range. All these beds occur low in the upper member of the Pound Quartzite, and they are correlated as a datum plane in Fig. 3. The fine-grained sediments are almost exclusively red beds from Mt. Scott Range in the north to south of Brachina Gorge but the lower portion is whitish sandstone at Bunyeroo Gorge and south (Fig. 4, A-C).

The picture of the Pound Quartzite as an uncomplicated, two-member formation is over-simplified, though there are only minor deviations from this norm in the area of the Parachilna 1:250,000 sheet and adjacent parts of the Orroroo 1:250,000 sheet to the south. These are:

1. Intermittent orthoquartzitic sandstones in the lower member; particularly thick beds are seen at Green Well Creek on the west flank and on the east flank at Wilkawillina Gorge, near Oraparinna Diapir.

2. The fine beds near the base of the upper member on the west flank.

3. Light maroon, haematitic sandstones occurring intermittently in the upper member particularly in Yappala Range and around Parachilna Gorge.

North of $30^{\circ}57'$ on the west flank of the ranges, the lower sediments become more sandy between Nilpena Hills and Green Well Creek on the south, and Red Range on the north. Section 9 (Fig. 3) is based upon thicknesses measured by Major (unpublished thesis, 1964) along the creek next south of Red Range water-bore, and in a direct line east. He did not make a large-scale subdivision of the Pound Quartzite but his data suggested, and further field study has confirmed, that the section could be divided into three units on the basis of upwardly decreasing frequency of red beds. These three units were, from the base: 140 m of haematitic, felspathic sandstones lithologically characteristic of the lower member; 248 m of interbedded, haematitic and orthoquartzitic sandstones; 257 m of mainly orthoquartzitic sandstones with minor red beds. Comparison of thicknesses with section 8 (Fig. 3) served to suggest that the two lower units at Red Range, together, are equivalent to the lower member to the south, and this was confirmed by the position of the fossiliferous bed. The outcrop at Red Range is duplicated across a N-S strike fault (Leeson, in Leeson and Nixon, 1966; Leeson, 1970, figs. 3, 4) but contrary to both publications the lower member as well as the upper outcrops west of the strike fault, though its base is truncated. The fossil bed is thinner and less rich in the eastern section than in the western; only the epichnial groove Form B (Glaessner, 1969), has been recovered east of the fault, while fossils listed in Table 1 have been found in the western outcrop. There the fossils occur through 11 m, in comparison with 3 m in the eastern outcrop where beds lack the finer sediment-sizes. Fig. 3 (9) is composite to the extent that the fossil beds have been shown as 11 m thick though the overall measurements have been taken from the eastern outcrop. As far as can be judged from pacing the sections, the thickness of the upper member is approximately the same in the western and eastern outcrops; the dip is 70°W in the west and 35°W in the east. The junction of lower and upper members is extremely weathered and the boundary is not definite in the west section but from 180-225 m of the lower member are present.

Leeson (1970, pp. 27, 28) described a section across Red Range but did not say where it was measured. Although he also subdivided the Pound Quartzite into three units, the lower two of which are equivalent to the lower member, his thicknesses cannot be reconciled with those of Major. This boundary between lower and upper member (Leeson, in Leeson and Nixon, 1966) occurs in the field precisely where it would be placed on Major's data. Leeson describes the base of the lower member as intertonguing with the Wonoka Formation, and also as being conglomeratic at the north end of Red Range, adjacent to Beltana Diapir. He could not recognize any pebbles from the diapir in his sediments but very little of the diapiric material is of striking lithology.

Threefold sequences like that at Red Range are also found at Randell Lookout in Ediacara Range and Mt. Scott Range, and, according to Leeson (1970), are general for the area of the Beltana 1:63,360 map. The sections measured at Randell Lookout by Major (unpublished thesis, 1964) and by Daily (1956) at Mt. Scott

Range are used in Fig. 3 (10, 11). Neither author attempted a major sub-division of the Pound Quartzite. When correlated with each other and with the fossil beds this threefold sequence fits the regional picture, as Leeson (1970) has said, provided the lower two units are correlated with the "lower, red member" of the sections to the south (Fig. 3 (1-8)). The fossil beds thus provide confirmation of the lithologic correlation in this region though elsewhere on the western flank the stratigraphic position has been used to show that the fossil beds form one band only. Leeson (1970, pp. 27, 28) also published a section through the Pound Quartzite at Randell Lookout which is not in close agreement with that of Major except for the overall thickness.

The topographically highest ridges in Red Range and Randell Lookout sections are white sandstones among the red and white sandstones. They replace the white member as the chief scarp-forming ridges here, though not at Mt. James as is clear from Goldring and Curnow (1967). At Mt. Scott Range, in a similar set of three lithologic types, the chief scarp-forming bed is again a white sandstone among the red and white sandstones, and once more the fossil beds occur in maroon sandstones and silts about 60-80 m above the base of the third unit (the dominantly white sandstones). This local variation points to an independent movement involving the Beltana Diapir complex, which preceded the regional shallowing of the deposition basin that terminated deposition of the lower member.

SECTIONS EXAMINED

The Western Flank

The type area of the Pound Quartzite, Wilpena Pound itself, has been investigated near Wilpena Chalet on the east side of the entry (Fig. 3 (4)) but here the bedding planes are often current-swept, and massive to coarsely laminated sandstones form the lower part of the upper member; indeed, it is massive throughout. It is the only section on the west flank where the fine-grained beds which are usually fossiliferous are known to be completely replaced by coarse sediments; though the sediments at Nilpena Hills tend this way, a few clayey laminae were present there. Sections which have been systematically searched for fossils have been plotted on Fig. 2 (1-21) but save for Wilpena Chalet, section 4, unfossiliferous sections are not illustrated in Fig. 3 for they have not been measured in whole or in part as have those that are illustrated. Two of these unmeasured sections have yielded fossiliferous float but nothing *in situ*: 13, Nilpena Hills, 27 km W of Green Well Creek, and 17, Patawarta Gap on the east flank of the Flinders Ranges, 25 km E by N of Green Well Creek. Possibly fossiliferous float was found at 12, Pullapa Spring. At 8, Green Well Creek, and 7, Parachilna Gorge, a more gradational change from lower to upper member is seen than that found to the south. From the commencement of dominantly orthoquartzitic sandstone deposition, it is interlayered with haematitic siltstones and sandstones for the first 4-5 m at Green Well Creek and the first 15 m at Parachilna Gorge. As the fossiliferous beds can be traced from the south to Green Well Creek the rather massive orthoquartzites below the transitional, banded bed there must represent the top of the lower member (Fig. 3 (8)), though they were mapped as belonging to the upper member which is covered by outwash on the north side of the creek. These massive orthoquartzites occur so high in the lower member that they can scarcely represent the sandstones associated with the Beltana Diapir (pp. 93, 94). There are nearer small diapirs (Fig. 2), Nilpena and Greenwell Diapirs being closest and both associated with Nuccaleena Fault (Leeson, 1970). Facies changes between Nuccaleena and Greenwell Faults and adjacent to Greenwell Diapir (Leeson, 1970, fig. 6) show that this diapir was moving in

late Lower and Middle Marinoan times, while the recorded movement of Nilpena Diapir was post Lower Cambrian. They outcrop on Nuccaleena Dome, a much larger structure which Leeson (1970) considers likely to overlie a large diapiric core of which they are apophyses.

At Parachilna Gorge some bands of haematitic sandstone are present throughout the lower three-quarters of the upper member; these, and interbedded white sandstones, are both rather sugary in texture and often become friable when weathered. In these last two characters the white sandstones of Green Well Creek and Nilpena Hills are similar. The upper one quarter of the upper member at Parachilna Gorge is as indurated and massive as is usual in the upper member further south, and the lower three-quarters is also massive (except for the fossiliferous beds) only a few km to the south (pers. comm. R. F. Harris).

The fossil beds at Brachina Gorge (Fig. 3 (6); table 1) are the richest part of the new outcrop but otherwise quite typical, and are detailed as an example (Fig. 4A). Total thickness of the lower member here is 340 m, and of the upper member 440 m. The fossiliferous section at Brachina Gorge begins 71 m above the base of the upper member and consists of the beds numbered 3-6 in Fig. 4A: (3) 10 m silty, fine sandstone with minor amounts of clay. Most is maroon but some laminae are slightly greenish white, (4) 3.3 m dense, massive, white sandstone with mud pellets concentrated near the base. To the south of a transverse fault which is hidden by scree except where it intersects Brachina Creek, this white sandstone is less massive, less well exposed, and possibly thinner but is still the only totally unfossiliferous subdivision of the "fossiliferous" beds, (5) 8 m silty, clayey sandstone, maroon coloured, with slump rolls of coarser maroon sandstone in the upper 1 m. (6) At least 3 m dense, massive white sandstone with slump rolls and occasional bedding planes that bear *Dickinsonia* fairly commonly and less often other fossils similarly "resistant" enough (Wade, 1968) not to have collapsed or decayed prior to the setting of the enclosing rock. The same lithology continues above (Fig. 4A (7)) but without fossils, although very rare bedding planes are found with surfaces whose smoothness indicates that the sand forming them was deposited against a fine-grained surface (Wade, 1968). These could preserve fossils but are very rare; their total exposed area is only a few square metres. No fossils are known. This same rarity prevails in the massive beds at every section examined. The cross-stratified to flat-stratified facies of the Pound Quartzite is normally deposited under too rigorous conditions of sediment-transport to preserve a soft-bodied fauna. On some rock faces even smooth surfaces showed evidence of sediment-transport which would have destroyed soft bodies; Wilpena Chalet and Patawarta Gap sections are samples of this—but nevertheless a piece of float with faecal pellets on it was found in the creek at Patawarta Gap.

At Bunyerroo Gorge (Figs. 3 (5), 4B) the fossil beds contain considerable fine-grained white sandstone which is largely barren but has fossiliferous layers intermittently in it. Fine-grained maroon sandstones to siltstones occur higher in the section, and the lower 6 m of coarser sandstones above the fine-grained sediments parts on bedding planes which are occasionally fossiliferous. The beds continue to the south, becoming coarser and unfossiliferous to the SSE in Wilpena Pound. They thicken considerably but remain fossiliferous to the SSW, where the greatest thickness of the fossil beds (112 m) was measured at Mayo Gorge, where Hookina Creek cuts through Elder Range, 15 km N of Hawker. This section is complicated by a number of faults and the lower part of the upper member is repeated four times. The most informative section (Figs. 3 (2), 4C) is in the block between faults F2 and F3. It is rather sparsely fossiliferous except near the top of the lower fossiliferous bed where the epichnial groove Form B is common

and medusoids are rare. In the same stratigraphic position between faults F3 and F4 quite a rich fauna was found (Table 1). The base of the section was absent from this block.

The more westerly section at Hells Gate (Fig. 3 (3)) is probably not as poorly fossiliferous as the record of only Form B would suggest. It is deeply weathered and leached white now, though it may have been partly red-beds prior to weathering. It does not part cleanly; its very floury texture indicates that chemically destructible, presumably clayey, material was present throughout the laminated, fine-grained silty sandstone. The Yappala Range section (Figs. 2, 3(1)), on the other hand, is really sparsely fossiliferous. As in Mayo and Bunyerou Corges, the fossiliferous beds are largely white, laminated sandstone with some maroon siltstone near the top. The fine-grained beds here are closer to the base of the upper member than in any other section, only 16 m above the lower member.

The section at Black Jack Range (Fig. 2 (21)) may yet prove to be sparsely fossiliferous; a short distance above its base, the upper member contains mainly very fine-grained maroon and white sandstones in a limited exposure. Chace and Druid Ranges to the northeast contain a similar sequence but it is badly weathered and badly exposed at sections 19 and 20, as on Mawson's line of section (1941). As the sequences are traceable into those at Yappala Range and Black Jack Range, respectively, they must be considered as potentially fossiliferous.

The Eastern Flank

There is much less outcrop of Pound Quartzite on this flank. This is partly due to Late Precambrian and early Cambrian erosion and/or non-deposition. The upper member is totally absent in the vicinity of the Oraparinna Diapir, as is the Parachilna Formation. Going northward, first the Parachilna Formation and then the upper member of the Pound Quartzite re-appear and thicken northward (Dalgarno, Johnson and Coats, 1964, 1:63,360 geological map, Blinman sheet). Section 18 at Wirrealpa Hill near Mt. Lyall was examined as it is one of the thickest sections of both members. Apart from some small circular shapes in the lower member which were probably due to mudflakes, no possible fossils were found. The mapped boundary between lower and upper members is not unequivocal in this section, it was placed by Dalgarno and Johnson (1966) at the lower of two positions that seem equally possible. This placement results in some medium to rather fine red and white sandstones being considered as low in the upper member in preference to high in the lower member. No fossils were found.

The Northern Flinders Ranges

Only the southern tip of this broadly V-shaped region was included in the area studied. The only previous record of Precambrian fossils in this area (Sprigg and Wilson, 1953) was of a single fossil jellyfish from 3.3 km ENE of Mt. Uno, in the Pound Quartzite of the NW flank of the Arrowie Basin, NE of Narina Basin (Fig. 2). About 33 km to the SW of this, on the SW side of Narina Basin, Patawarta Gap was investigated. The hill at the south side of the Gap (section 17) and the creek-bed were examined. The upper member is exposed as a series of four large questas of massive to flat-bedded, white sandstone. Exposure is almost total. Surfaces are current-swept or ripple-marked and fine sediments are lacking. The lithology most closely resembles the upper member in the Wilpena Chalet section where sediments also may have the winnowed appearance that results from medium to coarse sandstones, individually well-sorted. The underlying red, lower member consists of finer sandstones to siltstones and does not outcrop very well. It was not completely traversed. A sharp-edged piece of float bearing faecal pellets was found in the creek; this is a greyish sand-

stone with maroon surfaces like the haematite-coated flags from the lower fossil beds at Ediacara (Wade, 1968). In lithology it more closely resembled the lower member than the upper but it was less battered than float which had travelled 1 km down the creek from the upper member. Lateral transport from between two questas is suspected. This section is east and a little north of Green Well Creek, across an axial high with small exposures of diapirs. The most northerly fossiliferous occurrence known is the section 1.5 km E of Mt. Scott (Fig. 3 (11)). It has been discussed together with the correlation of other sections in the vicinity of Beltana Diapir (pp. 93, 94). Section 12 east of Puttapa Spring is also similar; it yielded doubtfully fossiliferous float though no fossils were found *in situ* there.

The syncline extending east from Patsy Springs Homestead past Angepena Homestead was investigated in two sections that proved to be ill-chosen (15, 16). The north limb, just south of Angepena Homestead, is overturned. It contains silty and clayey beds but these are somewhat deformed; sandstones among them are massive, and there is a general lack of flaggy sediments. They do not resemble the Mt. Scott section. The south limb, near Mt. Wallace, is a much thicker section of fine to dominantly medium and coarse sandstones with some pebble bands. The preliminary Copley 1:250,000 sheet shows it as a fault trough associated with the Mucatoona Diapir to the east and south. This diapir was apparently shedding sediment into the area during the time of deposition of the Pound Quartzite. Coats (1964b) described evidence of instability at the Patsy Springs end of the syncline just prior to the deposition of the Wonoka Formation.

The northernmost section studied (14) was that at Mundy Waters east of Leigh Creek, near Mt. Telford and just north of Boolooroo Diapir. Neither fossils nor fine-grained beds were found there. There was no clear-cut division into two or even three members. Sandstones tended to reddish and roughly flaggy in the higher beds and greyish and more massive in lower beds which were not continuously exposed.

OVERLYING SEDIMENTS

Parachilna Formation

In the Northern Flinders Ranges, both in the Angepena syncline and the Mundy Waters syncline, drab, olive-green siltstones with minor sandstones underlie the sandy facies of the "worm burrow beds" with *Diplocraterion* and other burrows. In the Mundy Waters section, above the drab, olive-green siltstones and interbedded barren, grey sandstones, the form Glaessner (1969) considered probably *Rusophycus* Seilacher is a common fossil in sandstones crowded with less characteristic trails. The facies and fauna is closely similar to that from near the top of the Arumbera Formation (Glaessner, 1969) and may similarly be lowest Cambrian in age. *Plagiognus* Roedel has also been recorded in this formation by Glaessner (1969), and Daily, Twidale and Alley (1969) who listed it from sections overlying the Pound Quartzite at Wilpena Pound. This not only reinforces the resemblance to the top of the Arumbera Formation where it also occurs (Ross River area, east of Alice Springs) but refines the Cambrian dating suggested by the probable *Rusophycus* by correlation with the Swedish occurrence (pers. comm. Martinsson, in Glaessner, 1969) which was probably from the Lower Cambrian of Kalmarund region.

In the Angepena syncline the drab, olive-green sediments are thicker than at Mundy Waters and contain some beds of dark grey, impure sandstones that are crowded with "worm casts" of various sizes and a bifid trail resembling that figured by Glaessner (1969, 9B, C). Most of the trails, however, are simple, unbranched and horizontal. Above them are cleaner sandstones typical of the *Diplocraterion* facies which contain some beds of remarkably deep burrows; they

reach 0.6 m deep. Shales again predominate in the beds above the clean sandstones. The olive-green siltstones and sandstones were only observed in these two Northern Flinders synclines, where they appear conformable with the more widespread *Diplocraterion* facies of the Parachilna Formation and to have been included in this formation by Dalgarno (1964) who mentions its "mappable contact" with the Pound Quartzite in this area. If we assume (Dalgarno, 1962; 1964) that the widespread occurrence of thick beds of the *Diplocraterion* sandstone facies is everywhere the same age, then the Parachilna transgression must have started earlier in the Northern Flinders. The total thickness varies from tens of cm to nearly 50 m in the southern area but increases to 370 m in the Arrowie syncline, SE of Angepena syncline (Dalgarno, 1964; Horwitz, 1962). The Parachilna Formation everywhere underlies the Wilkawillina Limestone (or the correlative Ajax Limestone, Daily, 1956; Dalgarno, 1964; Walter, 1967) and wherever investigated has above it a mid Lower Cambrian datum of relatively low in the Upper Aldan Stage. This datum was obtained by Walter (1967) from *Archaeocyatha* from the middle of the Wilkawillina Limestone. The base of the Wilkawillina Limestone is generally algal limestone and unzoned. From its stratigraphic position we have no cause to suspect a great age range within the Parachilna Formation which is probably all low Lower Cambrian.

OCCURRENCE OF EDIACARA FAUNA

The Ediacara fauna is thus separated from the Low Cambrian by the time taken to deposit 600 m (or more) of Pound Quartzite, a major erosional interval, and the time occupied by a (?mildly) diachronic transgression. The duration of these events is open to many interpretations. Probably our best method of dating the Ediacara fauna is through the gradually improving correlation with related faunal elements that have been dated overseas. This (Glaessner, 1966) currently gives an age around 600-700 m.y. It thus obliquely supports correlation of the Kimberley and Sturtian to Marinoan glaciations.

The known faunal content of the rocks is expanded by every collecting trip. To date, every single fossil is of a form known from Ediacara Range. The present count of species is listed under the section numbers of the localities in Table 1.

TECTONIC SETTING OF SEDIMENTATION

The distribution of the lower and upper members of the Pound Quartzite is not shown on the preliminary Copley 1:250,000 map but older map legends show it is recognizable over much of the area. The Cadnia 1:63,360 sheet (Grasso, Brock and Horwitz, 1960) mentions the reddish colour and shaley interbeds of the lower part. Sprigg and Wilson (1953) were even more explicit on the Angepena sheet (adjoining Cadnia on the north side): "Sandstone and quartzite slightly arkosic in part; principally light-coloured but thick reddish basal development particularly in the south westerly areas." The southwesterly area is part of the nose of the Mt. Scott Range syncline and the description indicates that the two members are no less distinct here than in sections 11 and 12 near Mt. Scott and Puttapa Spring; they may well be more distinctive, being further from the Beltana Diapir complex and the associated orthoquartzitic beds in the lower member (pp. 94).

Thompson (1969b) does not discuss the Pound Quartzite individually but figures it (fig. 27) as a coarser stipple overlying a finer one, both increasing in thickness to represent about 1,200 m of sediment each in the extreme north of Northern Flinders Ranges. This great increase in thickness implies differential tectonic movements over a long time and indicates that the shallowing and the supply of coarser sediments that resulted in the upper member of the Pound

TABLE 1

The known components of the Ediacara fauna and the areas from which they have been collected. Section numbers refer to Fig. 2. The entire fauna from Ediacara Range has been listed under section 10 for convenience. *"*Kimberia*" Glaessner and Wade, 1966, not *Kimberia* Cotton and Woods, 1935.

Section No.	1	2	3	5	6	7	8	9	10	11	12	13	17
body fossils:													
coarse, spicular impressions								x	x	x			
indeterminate medusoids		x		x	x	x		x	x	x	?		
<i>Ediacaria flindersi</i> Sprigg		cf		x	cf	x		x	x				
<i>Beltanella gilesi</i> Sprigg									x				
<i>Medusinites asteroides</i> (Sprigg)									x				
<i>Cyclomedusa davidi</i> Sprigg					x			x	x				
<i>C. radiata</i> Sprigg									x				
<i>C. plana</i> Glaessner & Wade									x				
" <i>C.</i> " sp.		x							x				
<i>Mucronites spriggi</i> G. & W.									x				
<i>Conomedusites lobatus</i> G. & W.					x				x				
* <i>Kimberia quadrata</i> G. & W.									x				
<i>Rugocorites enigmaticus</i> G. & W.					x				x				
medusoid, n. sp.				x	x				cf				
medusa, n. sp.					x				x				
<i>Lorenzinites rarus</i> G. & W.									x				
<i>Ovatosculum concentricum</i> G. & W.					x				x				
Chondrophore, n. gen., n. sp.									x				
<i>Rangia longa</i> G. & W.									x				
<i>R. grandis</i> G. & W.									x				
<i>Pteridinium simplex</i> (Gülich)					cf				x				
<i>Arborea arborea</i> (Glaessner)					x				x			cf	
<i>Dickinsonia costata</i> Sprigg		x			x			x	x	x			
<i>D. elongata</i> G. & W.		x			x				x	x			
<i>D. tenuis</i> G. & W.					x				x				
<i>Spriggina flindersi</i> Glaessner					x				x				
<i>Spriggina? ovata</i> G. & W.		x			x				x				
<i>Praecambridium sigillum</i> G. & W.									x				
<i>Parvancorina minchami</i> Glaessner					x				x				
<i>Tribachidium heraldicum</i> Glaessner		x			x				x				
trace fossils:													
<i>Pseudorhizostomites howchini</i> Sprigg		x			x			x	x	x			
Form A (Glaessner, 1969)					x				x				cf
Form B (Glaessner, 1969)		x	x	x	x	x	x	x	x	x			
Form C (Glaessner, 1969)									x				
Form D (Glaessner, 1969)									x		?		
Form E (Glaessner, 1969)		x							x				
Form F (Glaessner, 1969)					x				x				
3-point imprints (undescribed)					x			x	x				
+ ve trail (undescribed)	x	x							x				

Quartzite, are more probably the result of increased tectonism than some eustatic process. Glacial eustatic processes are most unlikely for the geologic instant was long after the deposition of the partly glacial Lower Marinoan Elatina Formation and the Middle Marinoan expansion of sedimentation which Thompson (1969b) suggested could be explained this way.

The six sections studied in the Northern Flinders Ranges (fig. 2 (11, 12, 14-17)) show more variability during Pound Quartzite sedimentation than is recorded in the Southern and Central Flinders ranges but 11 and 12 were associated in documented movements of Beltana Diapir, 15 and 16 with partly documented movements of Mucatoona Diapir, and 14 is very close to Boolooroo Diapir though only post-Lower Cambrian movements are yet documented for

that. Only Patawarta Gap (17) seems to have been in a stable area, and to differ from the southern and western sections only in its greater thickness.

The conclusion that the northern area was more actively subsiding than the southern is inescapable but the roles played by diapirism may appear more strongly differentiated than they actually were. Deep erosion in the axial region of the Central and Southern Flinders Ranges has removed the Cambrian and Upper Marinoan from the neighbourhood of a number of diapirs, and thus reveals more evidence of early movements of the diapirs there, and records less of their later movements. The less deeply eroded areas show more evidence of the younger movements while the older rocks are covered.

Shortly after the onset of coarser (upper member) sedimentation, an elongate deposit of fine sands with minor silts to clays formed (Fig. 3) west of what is now an axial high extending south from latitude $30^{\circ}45'$. The only definitive edge to the fine sediments is found at Wilpena Pound where massive sandstones like those at Patawarta Gap are in line with a low in the axial structure as at present expressed—a gap between two diapirs that had commenced movement by the Sturtian (Dalgarno and Johnson, 1966). The more northerly of these continued its movements intermittently into the Cambrian (Oraparinna Diapir, Dalgarno, 1964; Walter, 1967). No post-Sturtian rocks are associated with the more southerly. All of the larger diapirs on this axis have histories of movement dating back to the Sturtian, except Beltana Diapir which is surrounded by Middle and Upper Marinoan rocks to both of which it contributed coarser sediments. The observations of Coats (1964a) and Dalgarno (1964) on the extent of the movements receive additional documentation from the maps of Dalgarno and Johnson (1966) and Leeson and Nixon (1966) and from Leeson (1970). After the short, and variously interrupted, period of deposition of fine sediments the area returned to the deposition of coarse- to medium-grained, white sands, strongly cross-bedded and ripple-marked, and with intermittent slump rolls—the cross-stratified to flat-stratified facies of Goldring and Curnow (1967).

Alternative explanations for this distribution of fine sediments must take decreasing effect of water movement into account. This could have been caused either by the deepening of the water column over the region of the present Mt. Scott syncline, west flank area and Chace and Druid syncline, or by the formation of barriers reducing wave action. Though in this region only the Beltana Diapir shed boulders into the Pound Quartzite—and that earlier than the widespread change of sedimentary pattern in the south—it hardly seems possible that a general shallowing could affect the basin without re-activating at least some of the pre-existent diapirs. Frome Diapir, east of Mt. Lyall, was eroded at this time (Coats, 1964a). The formation of sheltered areas of sea floor on the landward (west) side of shoals in the general position of re-activated, known diapirs seems the most likely explanation of the short-lived deposition of fine sediments in this shallow sea. Erosion in the axial region has proceeded to a depth that has removed most evidence but statistical work may show maxima in the direction of movement of slump rolls, for instance, which would show the direction of the high or highs that shed them. At Parachilna Gorge they even occurred intermittently during the deposition of the fine sediments.

OUTLYING OCCURRENCES

Two single specimens, each of a pennatulid on a loose rock slab, have been found beyond the confines of the Adelaide Geosyncline (Text-fig. 1; x, y). *Arborea arborea* (Glaessner) was found at locality x, $27^{\circ}45'$, $130^{\circ}30'$, in the uppermost Precambrian Punkerri Sandstone which is correlated with the Pound

Quartzite but not well exposed (pers. comm., R. B. Major). *Rangia* cf. *longa* Glaessner and Wade was found at locality y, east of Deep Well Homestead, 80 km SSE of Alice Springs, in the lower part of the Arumbera Sandstone (Glaessner, 1969). The specimen is identical with Ediacara specimens lacking preserved secondary branches (anthosteles); these have similarly been called *Rangia* cf. *longa*.

The Arumbera Sandstone is Lower Cambrian at its top (Glaessner, 1969) and is conformable with the Precambrian Pertatataka Formation (Wells, *et al.* 1967; Forman and Milligan, 1967, maps only, pls. 10-13). These authors provisionally considered the entire formation Cambrian though Wells *et al.* noted that the base could be Precambrian. The known fauna consists mostly of the trails and burrows described by Glaessner (1969) mainly from a bed about three-quarters the distance from bottom to top of the formation, and higher. (The existence of two published variants of the thickness in the Laura Creek region, 23 km WSW of Alice Springs, 600 m and 430 m, leads me to prefer to render the relative positions as ratios). The commonest trace fossil, by field observation, is a small diameter, unnamed burrow filling (Glaessner, 1969, fig. 6E) which also may occur in the finer sediments right down to (but not in) the lowest ridge-forming sandstone a little less than one quarter the distance from base to top. About two-thirds of the distance from the base to top the well-preserved but undescribed medusoid collected by G. K. Williams was obtained (Glaessner, 1969; G. K. Williams, pers. com.); one specimen of an epichnial groove inseparable from Glaessner's Form B in the Ediacara fauna was collected half way through the formation, and a few *Hallidaya brueri* Wade from one quarter the distance from base to top (Wade, 1969). The *Rangia* from Deep Well was said to be from near the base of the Arumbera sandstone.

The known fauna may be summarized as: one form known from the Ediacara fauna from near the base, 2 medusoids not known from the Ediacara fauna and 2 trace fossils with overlapping ranges, one previously known from the Ediacara fauna and one from the Cambrian, from the central part of the formation, and several Cambrian trace fossils from the upper quarter. Thus whether we accept the evidence of bridging of the Cambrian to Precambrian boundary or not, we have elements of a fauna which must represent at least the upper part of the time unrecorded in the Adelaide Geosyncline, due to the unconformity between the Pound Quartzite and Parachilna Formation.

Webby (1970) has comprehensively described the lately-discovered trace fossil faunas of the Fowlers Gap Beds and the Lintiss Vale Beds in north-west New South Wales (Fig. 1z). It is unfortunate that not many of his forms are very distinctive but most satisfactory to have a description of the complete fauna.

Webby noted that about 3 times as many kinds of activity were present in the upper fauna (from the Lintiss Vale Beds) as in the lower (Fowlers Gap Beds) fauna. He pointed out that the same conclusion could be derived from his material as from literature, that the trace fossil faunas become richer as the Cambrian is approached. Glaessner (1969) came to the same conclusion from comparison of literature, the Precambrian Ediacara fauna trace fossils and the definitely low Lower Cambrian Arumbera Sandstone fauna. Webby based his decision that he was dealing with a Precambrian fauna on the absence of Arthropod markings and most complex burrows, though he noted some typically Cambrian forms, a new *Phycodes*? and bilobed and trilobed trails in his upper fauna. His Fig. 11 could be a fragment of *Platygomus* which is sometimes preserved as a burrow filling but even disregarding this possibility there are close resemblances between the Parachilna-Arumbera fauna and the Lintiss Vale fauna. *Phycodes*? *antecedens* Webby is admittedly close to *Phycodes pedum* Seilacher

which occurs in the Arumbera and possibly is also present in the Parachilna Formation at Mundy Waters. The bilobed trail (Webby, 1970, Fig. 12A,B) appears identical with the Parachilna Formation form figured by Glaessner (1969, Fig. 9B, C). *Planolites ballandus* Webby (1970, Fig. 14A, C) can be duplicated from the Arumbera Sandstone. *Gordia* sp. of Glaessner (1969, Fig. 9E) is an external mould identical in shape and size to *Cochlichnus serpens* Webby. Small, curved trails differing from *Torrowangea rosei* Webby by the pellets being less closely packed and the curves smoother and more open, occur below the richly fossiliferous sandstone three-quarters the distance from bottom to top of the Arumbera Sandstone.

The aspect of the Lintiss Vale trace fossil fauna is more like the low Lower Cambrian fauna than the Ediacaran. If further collecting fails to produce more of the Cambrian element in the fauna, its age will have to be considered intermediate between the low, Lower Cambrian and the Ediacara fauna. The Ediacara fauna must be re-sought below the Lintiss Vale Beds. The Fowlers Gap fauna would not appear out of place in the Ediacaran but is too poor in date.

CONCLUSIONS

The long-awaited evidence on the stratigraphic placement of the Ediacara fauna has been provided by a band of fossiliferous rocks near the base of the upper member of the Pound Quartzite. This so closely parallels the boundary between the lower and upper members as to entitle us to regard this boundary as a time plane through the western side of the Flinders Ranges. It also highlights the tremendous amount of erosion that took place on the locally inconspicuous unconformity between Pound Quartzite and Parachilna Formation. The thinning of the lower member at Ediacara Range has to be regarded as a depositional thinning since both the typical "lower member" beds and the "red and white sandstones" above them are thinned in the same proportions relative to the Mt. Scott and Red Range sections. The upper member could owe its thinning here only to erosion (Fig. 3 (10)) as the beds below the fossils are of average thickness, but erosion has removed the evidence.

Evidence of repeated movement on the diapiric cores from Sturtian to post Lower Cambrian continues to mount. It appears clearer that the major stratigraphic highs seen in the zone of diapirism today have been highs repeatedly since the Sturtian and were not re-elevated by chance in the lower Palaeozoic folding of the geosyncline.

The discovery that a low Lower Cambrian fauna in the upper quarter of the Arumbera Sandstone is correlatable to the Parachilna Formation (Glaessner, 1969) reveals the fact that the differing fauna in the middle of the Arumbera Sandstone represents a zone above the Ediacara fauna. Whether this should be assigned to the Cambrian or the Precambrian will await inter-regional correlation. The discovery of a fauna of about this age near the top of a continuous sequence in northwest New South Wales (Webby, 1970) gives a second possibility of establishing the Precambrian-Cambrian boundary in a continuously zoned succession, as has been done with later era boundaries. This area may provide a suitable subsidiary section for the top of the Upper Marinoan.

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THE SUBLITTORAL ECOLOGY OF WEST ISLAND, SOUTH AUSTRALIA

1. ENVIRONMENTAL FEATURES AND THE ALGAL ECOLOGY

BY S. A. SHEPHERD[†] AND H. B. S. WOMERSLEY*

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On rough shores three zones are evident but on the sheltered lee shore the uppermost zone is very restricted and the lowermost zone does not occur due to the limited water depth. The upper sublittoral zone is colonised by a short red-algal turf comprising species tolerant of turbulent water and strong light, with a sublittoral fringe of *Cystophora intermedia* present only in the roughest areas. The mid sublittoral zone is dominated by larger brown algae and the lower sublittoral by a mixed association of red algae growing under conditions of low light and slight surge.

Water movement and light are probably the two most important ecological factors in the sublittoral. Horizontally species' range is largely determined by water movement but vertically light is the more important; however, it is evident that the mid sublittoral zone of large brown algae occurs at greater depth under rougher conditions, and several other species follow this pattern.

The depth range of most species can vary considerably depending on the interplay of light, water movement, aspect and probably other less conspicuous factors.

Estimates are given of the standing crop of algae within various associations.

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On rough shores three zones are evident but on the sheltered lee shore the uppermost zone is very restricted and the lowermost zone does not occur due to the limited water depth. The upper sublittoral zone is colonised by a short red-algal turf comprising species tolerant of turbulent water and strong light, with a sublittoral fringe of *Cystophora intermedia* present only in the roughest areas. The mid sublittoral zone is dominated by larger brown algae and the lower sublittoral by a mixed association of red algae growing under conditions of low light and slight surge.

Water movement and light are probably the two most important ecological factors in the sublittoral. Horizontally species' range is largely determined by water movement but vertically light is the more important; however, it is evident that the mid sublittoral zone of large brown algae occurs at greater depth under rougher conditions, and several other species follow this pattern. The depth range of most species can vary considerably depending on the interplay of light, water movement, aspect and probably other less conspicuous factors.

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INTRODUCTION

Although the intertidal ecology of the southern Australian coast is fairly well known (Bennett & Pope 1953, 1960; Womersley 1947, 1948, 1956a; Womersley & Edmonds 1952, 1958), the only study within this region of the subtidal algal ecology and distribution, based on collections made in situ, is that in the almost enclosed Port Phillip Bay, Victoria (Womersley 1966).

This contrasts with the situation in the northern hemisphere where pioneer studies in subtidal ecology were made by Gislén (1930) in a Swedish fjord, using helmet diving equipment, and by Feldmann (1937) in the Mediterranean. With the advent of SCUBA equipment, sublittoral surveys have been carried out on many coasts, including those of Europe (Forster 1961, Jorde 1966, Kain 1960, Kitching 1941, Söderström 1965), the Mediterranean (Crossett & Larkum 1966, Pérès 1967, Vacelet 1967), Asia (Petrov 1967, Vozzhinskaya 1965), North America (Edelstein et al. 1969, McLcan 1962, Neushul 1965), New Zealand (Bergquist 1960a,b) and the Antarctic (Zaneveld 1966).

Thus knowledge of subtidal marine organisms and their ecology in Australia is largely limited to the uppermost sublittoral as observed during very low tides or by shallow diving and visual observation from the surface. The sublittoral on rough coasts, which comprise most of the southern Australian coastline, is virtually unknown, though the rich algal flora has been fairly well documented from drift collections.

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The ecology of subtidal communities of marine algae and sea-grasses is of basic importance in many marine studies and, together with floristic studies of such communities, is a valuable indicator of the biogeographic relationships of a region. Subtidal, rather than intertidal, organisms are probably better for this purpose since they are not subject to the extremes of temperature and other conditions in the intertidal region.

West Island was chosen for study because of its easy accessibility yet suitable position subject to rough conditions with no protection from the south-west. Biotic communities on such off-shore islands generally have a richer flora and fauna than communities in more sheltered waters. This is probably because physical conditions in the water are more favourable and less variable. While water movement is usually greater around off-shore islands, fluctuations in temperature, salinity, oxygenation and turbidity are smaller and sand scour is almost absent. West Island is of a suitable size for a study of the effect of wave action which varies greatly from windward to lee shores around the island; also the presence of steep under-water slopes permits a study of communities in relation to depth.

The aspect of subtidal rock surfaces is of considerable importance. Upward facing surfaces are dominated by algae but, as a rock face approaches the vertical, faunal elements increase and algal density decreases. In caves, crevices and under overhangs, algae are mostly absent and animals predominate, as has been described by Cressett & Larkum (1966), Pérès & Picard (1949) and Vacelet (1967). This is due almost entirely to low light intensity and re-emphasizes that algae usually dominate the photic zone while animals dominate places where light is inadequate for plant growth. While some animal communities do occur within the photic zone, division of synecological studies into faunistic and floristic aspects is convenient. In the following account, horizontal and sloping to vertical surfaces are considered, but not other surfaces subject to reduced light where the fauna predominates. The animals which are prominent among the algal communities are mentioned briefly.

This account of the subtidal algal vegetation of West Island is of more than local interest, since many of the communities and the basic zonation are found elsewhere in rough areas of the central coast of South Australia. The intertidal zone is excluded from this account since the discussion of Womersley and Edmonds (1958) for rough to sheltered, steeply sloping coasts applies to West Island.

METHODS

The survey on which this study is based was carried out by the first author with SCUBA equipment between December 1965 and May 1968, with occasional observations since then. The island was visited on fifty occasions at fortnightly or monthly intervals during the study period and more than seventy hours were spent underwater. Notes were taken on sand-blasted perspex and algal (and faunal) collections were made at numerous localities about the island. Determinations of algae were made by the second author. Specimens of all species are lodged in the herbarium of the Botany Department, University of Adelaide (ADU).

All depths given in this paper are in metres and are based on the low water neap tide level for Victor Harbor. This "datum level" is used for Figures 7-14 and the eulittoral—sublittoral boundary varies from this as indicated on Figure 6.

Initially, a general survey was made of the area and the algae collected for identification. Then followed a more careful survey and the relative abundance

and range of individual species were noted. Finally, quantitative estimates were made of the density of algae at several points about the island.

The continuous south-west swell made collecting difficult and hazardous on the southern and western shores, and the upper sublittoral zone at these localities was only accessible after days of protracted calm weather. On only two occasions during the period was the swell low enough to permit diving at upper levels at Lands End.

AREA SURVEYED

West Island (Pl. 1) is a granite knoll of about 13 hectares (33 acres) rising to a height of 40 m, about 800 m offshore at the north west end of Encounter Bay (Lat. $35^{\circ}37'$, Long. $138^{\circ}35'$). The island is figured and its geology discussed by Howchin (1910, p. 7, pl. XI). Some prominent features on the island and locality names used during the survey are shown in Figure 1 and Plate 1. Along the windward southern face, steep cliffs fall abruptly to the intertidal and continue to a sandy sea floor at a depth of about 29 m. Underwater the granitic blocks have broad sloping faces and form between them crevices, caverns and overhangs.

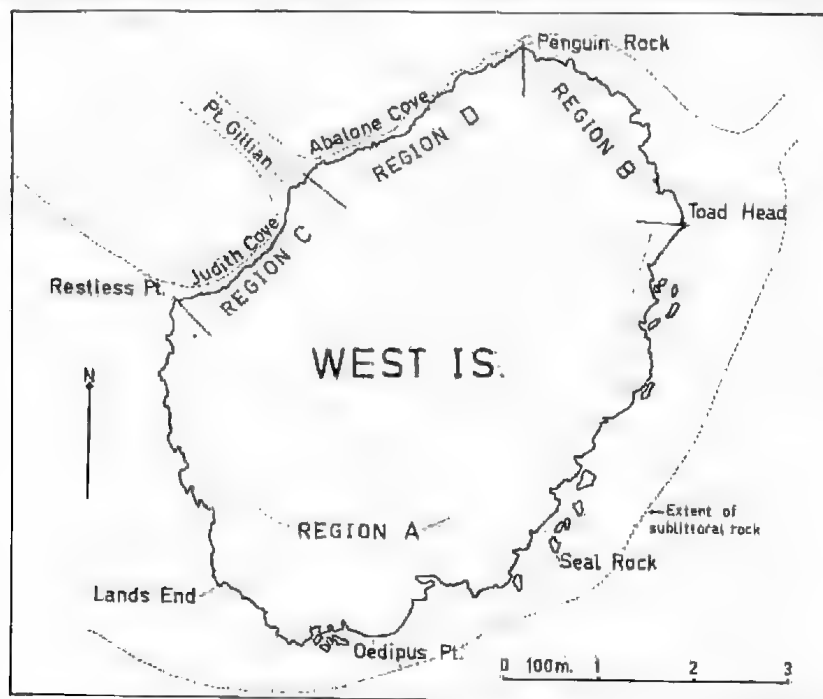


Fig. 1 Map of West Island.

While the underwater topography provides many different microhabitats with a great diversity of plants and animals, there are also extensive areas of uniform algal growth. Along the eastern and western shores the sea floor gradually rises (see Figure 4). The continual breakers on much of the western shore prevented a detailed examination of the sea floor. The northern shore of the island between Restless Point and Penguin Rock is low and slopes to the sea bed at about 5 m. In many places rounded granite boulders up to 50 cm across lie down the slope and are scattered on the bottom, and two shallow rocky sills run shorewards at a depth of about 3 m. To the lee of the island, extensive beds of marine angiosperms stabilize the sandy sea-bed.

ENVIRONMENTAL FACTORS

(a) *Temperature*

West Island is reported to lie between the summer and winter surface sea isotherms of 19° and 13°C (Womersley and Edmonds 1958). Temperature readings were taken from the surface to the bottom at 5 m intervals in the open sea outside the island, at monthly intervals for three years. Figure 2 shows that the annual range in surface temperature is about 8°C . Surface temperature readings from the winter of 1967 until the winter of 1968 were relatively high, averaging about 2°C above those recorded in the previous two years, while summer temperatures in 1969 and 1970 were lower, the highest readings being 19.5°C .

Temperatures did not vary greatly from the surface to the bottom. A thermocline was sometimes recorded between 15 and 20 m during calm periods in summer when the surface water was from 1.3°C warmer than deeper water. This was no doubt due to the heating by radiation of the upper water column, together with lack of mixing. Conversely, in late autumn, the surface waters cooled more quickly and were sometimes up to 1°C cooler than the water between 20 and 28 m. Between July and October a bottom layer of turbid water up to 3 m thick was sometimes found to vary up to 1°C above or below that of the superjacent water.

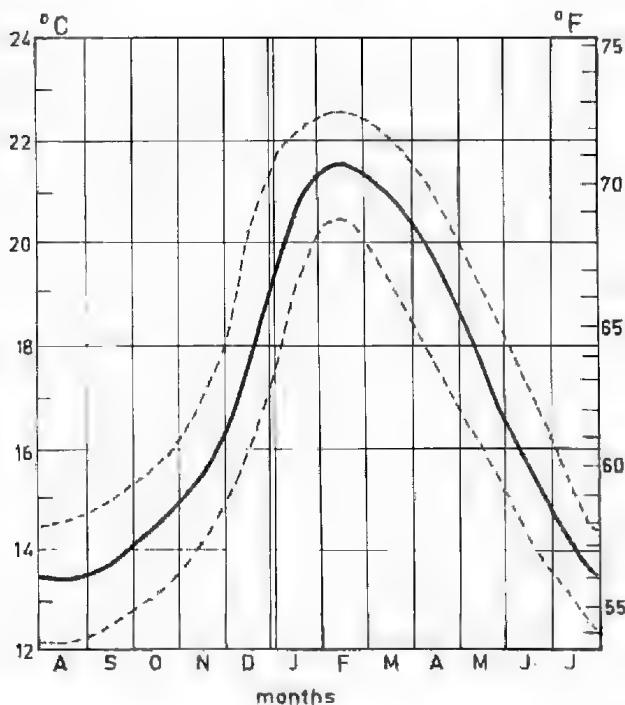


Fig. 2 Sea surface temperatures in 1965-67 taken 20-30 m off the south-east coast of West Island. The broken lines indicate the extreme range, and the solid line shows the averages for the period.

(b) *Waves, Swell and Surge*

Wave energy reaching the island is of three main types

- (i) *Prevailing Swell*. This is generated in the Southern Ocean well south of the continent and prevails throughout the year; the direction of approach is south-west.

- (ii) *Local Seas*. These are caused by local winds. When the winds are offshore (i.e. from the east through north to west) waves of short wave length (period < 3 seconds) are generated. These produce no surge and are of little significance in the sublittoral zone. On-shore winds produce waves which combine with the swell and reinforce it.
- (iii) *Local Swell*. In early summer (November and December), the prevailing winds are from the south to south-east. During these months a short swell is generated from that direction with a period of 5 to 6 seconds. This may be superimposed on the prevailing swell causing the combined swells to periodically reinforce each other. Local swell is unusual at other times of the year.

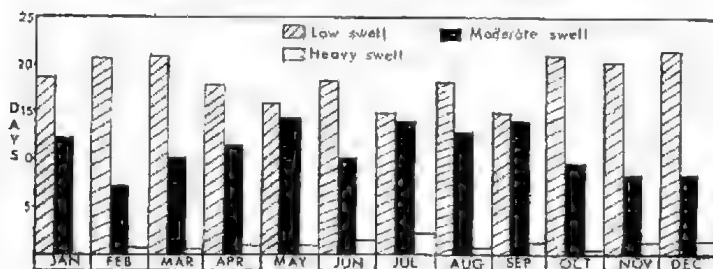


Fig. 3 Average monthly distribution of days of low, moderate and heavy swell for the years 1965-1967 at Neptune Is.

Prevailing swell conditions from 1965 to 1967 as recorded at Neptune Island (at the southern end of Spencer Gulf) are shown in Figure 3 and indicate the situation at West Island. Although oceanic swell is on the average more severe during winter, periods of very low swell may occur at any time of the year.

The observed swell characteristics are shown in Table 1. Wave lengths were determined from aerial photographs.

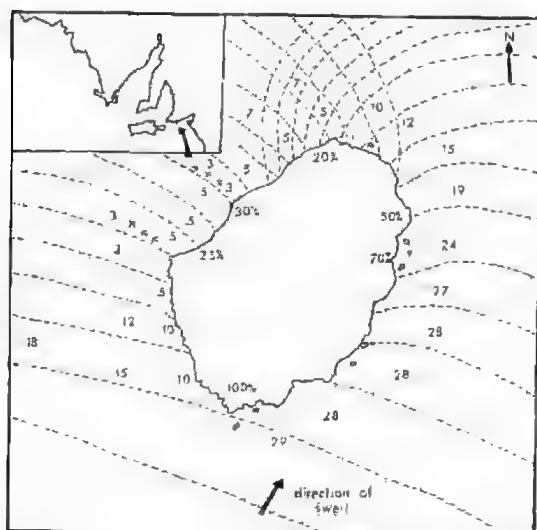


Fig. 4 Successive wave crests (broken lines) about West Island. Figures (within the island outline) are wave heights expressed as percentage of maximum height at Lands End. Depths are in metres. The position of West Island is shown on the inset map of the South Australian coast.

In this paper the term "surge" is used to refer to the rapid sub-surface horizontal water movements with abrupt reversals of flow caused by the swell as it passes over shallowing water. In deep water, as a wave passes, any particle of water describes a circle the radius of which decreases with depth. However, on approaching an island barrier the water will surge to and fro more or less horizontally. This effect is most severe near the surface and decreases with depth.

TABLE 1
Observed prevailing swell conditions at West Island

Swell	Wave Height Range (metres)	Period (seconds)	Wave Length (metres)
Low Moderate Heavy	(0.5 —) 1–2 2 — 3 over 3	} 10 — 12	} 110 — 120

The degree of water movement is of great significance in its effect upon algal growth but it has not yet been satisfactorily measured. The methods of Jones and Demetropoulos (1965, 1968) and Muus (1968) are not readily applicable to under-water studies. Despite the lack of accurate measurements, biological indicators and some local knowledge will generally enable a reasonably good assessment of surge conditions to be made. There is no doubt that occasional very rough seas do more damage to algae by mechanical action of surge than do average conditions.

The prevailing swell strikes the island on the southern and western shores, reaching maximal force at Lands End. The distribution of wave height about the island is controlled largely by diffractive effects although on the northern shore some wave refraction occurs inshore (see Figure 4). The two submerged reefs on the northern shore and the dense sea-grass meadows in shallow water cumulatively attenuate the swell so that in Abalone Cove it is reduced to about 20% of its original height. At Abalone Cove the waves passing around each side of the island intersect, resulting in a continual though slight surge. Figure 4 shows successive wave crests and estimated wave heights at various localities expressed as a percentage of wave height at the roughest location.

(c) *Visibility and Submarine Illumination*

The island is washed by oceanic water which is virtually free from suspended silt discharged from mainland rivers. Occasionally (usually September to November) after strong southerlies, tongues of turbid water may extend westward from the River Murray mouth (about 24 km to the east) to the vicinity of West Island, but these are rapidly dispersed by a change in weather.

TABLE 2
Underwater Visibility off West Island

Conditions	Visibility at depth of	
	0 — 20m	20 — 29m
1. <i>October to February</i>		
Low Swell	7 — 12m	2 — 5m
Moderate Swell	About 5m	1 — 2m
2. <i>March to September</i>		
Low Swell	10 — 15m	3 — 10m
Moderate Swell	5 — 7m	1 — 2m

Visibility is fairly uniform down to about 20 m but below this drops sharply. The degree of turbidity is related to swell conditions. Bottom sediments are stirred up through agitation of the sea-bed by surge and water turbidity is greatest near the bottom, depending on the duration and severity of the swell. The approximate range of visibility during the year is shown in Table 2. After a prolonged calm, visibility near the bottom may rise to the maximum shown in the Table but usually lies between 1 and 4 m.

Water transparency was found to be generally lower during summer than at other times. An increase in plankton may be responsible for the reduction in transparency, but this has not been investigated.

Light readings using a photometer in a watertight case were taken from the surface to the bottom at 5 m intervals outside the island, monthly for 12 months. The readings were all taken with the sun at zenith and with a clear sky. Light intensities vary according to water turbidity and the range in values down to 26 m (expressed as a percentage of subsurface illumination) is shown in Figure 5. The illumination for clearest and average oceanic water and for average coastal water (after Sverdrup et al. 1942, p. 776) is also given in Figure 5 for comparison. The transmission values for the waters off West Island lie between the values for average ocean water and average coastal water.

In addition the horizontal illumination was measured at various depths to determine the intensity of light falling on a vertical rock face (Poole and Atkins 1929, Strickland 1958, p. 472). The ratio of horizontal to downward illumination at various depths is shown in Table 3. The highest percentages were recorded from waters of average transparency and the lowest from turbid water; the percentages for very clear water were slightly below the averages recorded. On rare occasions, however, near the bottom, light reflected upward from the sand increased the level of light by as much as 50%.

TABLE 3
Ratios of horizontal to downward illumination at various depths expressed as a percentage of downward illumination

Depth (metres)	Subsurface	6	13	19	26
Extreme Range (%)	20 — 25	25 — 75	10 — 50	10 — 40	10 — 25
Average %	24	38	33	21	17

(d) *Scour and Sedimentation*

Scour by sand does not occur due to the absence of surge at the sublittoral base of the island where rock meets the sand. The waters of these rough shores are free from sediment, so that silt is absent from rock surfaces to at least 25 m. Below this depth sediments stirred up by swell may sometimes settle on rock. On the lee of the island also, sediments of fine sand may accumulate on a horizontal rock surface which is in an exceptionally protected site.

(e) *Other Factors*

No measurements were made of salinity, phosphate, nitrate, alkalinity or of the level of dissolved oxygen. The figures given by Womersley (1947, p. 235) for the south coast of Kangaroo Island are probably applicable to West Island. Kirkwood (1967) gives figures for organic phosphorus, inorganic phosphate and nitrate in South Australian waters. These factors are so stable that they are unlikely to contribute to community differences in the region studied.

TERMINOLOGY

With the probable development of further underwater studies, there is a need for uniformity in terminology. The proposals made here are applicable to southern Australian coasts and accord with observations made elsewhere by many other authors.

(1) *Horizontal Distribution*

On rough coasts of southern Australia surge is a principal factor affecting algal distribution (Womersley 1947, p. 236) and hence a classification of the benthic-plant environment should be related to this factor. The coastal sub-formations of Womersley (1947) might be adapted for sublittoral conditions as follows:

Rough coast sub-formation (i.e. subject to prevailing swell).

- (i) Strong to extreme surge.
- (ii) Moderate surge.

Womersley's "sheltered rocky coast sub-formation" then refers to a coast subject to a slight surge caused by swell or by wind-driven waves of short wave length. Bennett and Pope (1960, p. 221) use similar degrees of roughness and take the wave strength at Cape Bridgewater as a standard maximum. Wave action at Lands End, although not as severe as that at Cape Bridgewater, is of the same order.

(2) *Vertical Zonation*

A sharp distinction between zones is less apparent in the sublittoral than in the intertidal zone and plant zonation is seen rather as a gradation from one association to another. Nevertheless Jorde and Klavestad (1963) and Nenshul (1965) describe three vertical algal zones and Bergquist (1960a,b), McLean (1962), Jorde (1966), Petrov (1967) and others describe an upper and lower zone in the sublittoral. In southern Australia usually three, sometimes two, zones according to locality and roughness, can be recognised. Figure 6 illustrates the terminology used. Most writers recognise similar vertical subdivisions (see Hedgpeth (1957, p. 19) and Petrov (1967) where the terminology used by various

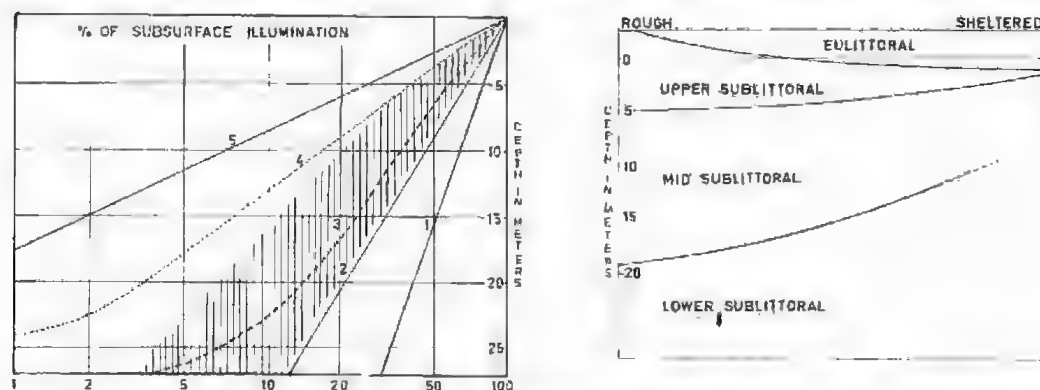


Fig. 5 Range in transmission values for waters off West Island during low swell are shown in the shaded area. Other values are: 1. Clearest ocean water (after Sverdrup). 2. Average ocean water (after Sverdrup). 3. Average of values recorded during low swell. 4. Most turbid water recorded during moderate swell. 5. Average coastal water (after Sverdrup).

Fig. 6 Zones of the sublittoral showing the depth variation from rough to sheltered water.

writers is summarised), the differences between them being in naming of the zones only. Pérès (1967) discusses a similar scheme based on intensity of water movement at different depths.

The term "upper sublittoral" refers to the upper zone which on most coasts is characterised by a short algal turf but on rough coasts in the cooler waters of Victoria and Tasmania is dominated by the "bull-kelp", *Durolleia potatorum*. On rough coasts the zone may descend to 5 m; in these conditions the highest part, emergent between waves at low tide, is characterised by distinctive species (e.g. *Cystophora intermedia*) and is referred to as the sublittoral fringe (Womersley and Edmonds 1952; Bennett and Pope 1960, p. 198).

The mid and lower levels of the sublittoral are characterised by communities of brown algae and red algae respectively.

These zones are biologically characterised entities and their boundaries vary according to the physical conditions. Figure 6 shows the shift in boundaries from rough to sheltered conditions. The most striking effect is that under sheltered conditions the upper sublittoral zone of algal turf is very narrow and the mid sublittoral zone of brown algae extends to low tide level.

(3) Association and community

The term "association" is used as in intertidal ecology (e.g. Womersley 1948) to refer to distinctive groupings of one or more species occurring repeatedly in a particular environment. The term "community" is less precise and refers generally to moderately distinct aggregations of plants. Further characterisation of ecological groupings in the sub-littoral must depend on future studies and at this stage more precise definitions are not attempted.

ZONATION AND DISTRIBUTION AROUND THE ISLAND

The general features of the algal vegetation change markedly around the island in passing from rough to more sheltered coasts. The shores have therefore been divided into four regions, each of which has algal communities with characteristic features. The changes in the vegetation from one region to another are seldom sharp yet occur over a relatively short distance, indicating a distinct gradient in one or more environmental factors.

- (I) *Region A*. The rough-water southern and western coasts between Toad Head and Restless Point.
- (II) *Regions B and C*. The moderately rough-water disjunct sections on the eastern and northern shores.
- (III) *Region D*. The semi-sheltered section in Abalone Cove.

(1). REGION A (ROUGH WATER)

Wave action is generally strong and reaches its greatest force on the south-western side. Here the splash zone extends upwards to more than 20 m above sea level and the littorinid snail *Melaraphe unifasciata* (Gray) is common at this height. In conditions of such extreme roughness, both the eulittoral zone and the upper boundary of the sublittoral zone are elevated relative to mean sea level (cf. Söderström 1965), and *Cystophora intermedia* which has been used as an indicator of the upper boundary of the sublittoral (Womersley and Edmonds 1958) forms a narrow belt (sublittoral fringe) up to a metre wide. A vegetation profile down to 27 m in an area of extreme roughness at Lands End is given in Figure 7.

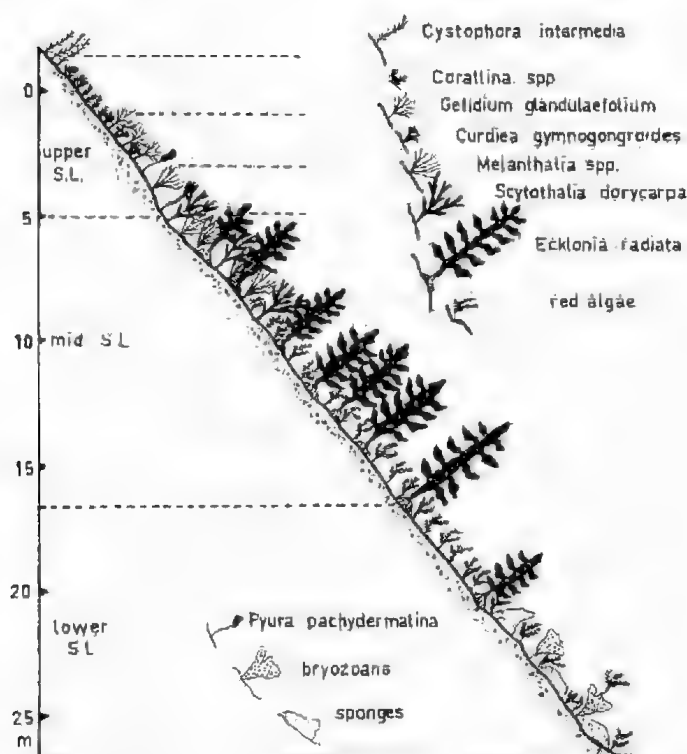


Fig. 7. A vegetation profile near Lands End (very rough). Three belts in the upper sublittoral are indicated by broken lines on the right of this zone.

Upper Sublittoral Zone (to 3-5 m deep)

A strong surge exists down to at least 12 m and it is seldom possible to examine underwater the region just below low water level. The zone is clearly defined and extends vertically down to between 3 and 5 m according to the degree of water turbulence. Along the western shore, on sloping faces, the zone contains three distinct horizontal belts.

- (1) The uppermost is colonized by *Corallina* sp. and encrusting lithothamnium down to 1 m. *Pterocladia capillacea* occurs where there is local shelter near Restless Point. The corallines form a community with the barnacle *Balanus nigrescens* (Lamarck) and the chiton *Poneroplax costata* (Blainville). Occasionally, the mollusc *Dicathais textilis* (Lamarck) is also seen. The upper limit of the belt is indicated by *Cystophora intermedia* which, on horizontal rocks, forms a dense community but on sloping rocks occurs only in scattered clumps. This community also extends above *Cystophora intermedia* to form the lower eulittoral zone (see Womersley and Edmonds 1958) and it is now apparent that on such rough coasts there is a fairly uniform coralline mat—*Balanus* association extending for some distance above and below the low tide region (through and beyond the 'suck back' region) with a superimposed belt of *Cystophora intermedia* occurring where it is subject to momentary emergence at low tide.
- (2) Below the corallines, there is a well defined middle belt comprising a mat chiefly of *Gelidium glandulaefolium* and *Curdiea gymnogongroides*. This mat extends to the lowest part of the zone but in its lowest 2 m tends to be overshadowed by more prominent species of the belt below.

- (3) The lowest belt is characterised by larger algae, including *Melanthalia concinna*, *M. obtusata*, *Sargassum bracteolosum*, *Zonaria sinclairii* and occasionally *Scytothalia dorycarpa*, and forms a transition zone to the mid sublittoral zone dominated by *Ecklonia radiata*. The stalked ascidian, *Pyura pachydermatina* (Herdman) var. *gibbosa* Herdman is common below about 2 m.

Where the rock face drops vertically into the sublittoral and on much of the steep and shaded southern shore, three distinct belts are not evident. Probably due to the lower light intensity, corallines are scarce and the upper sublittoral is dominated by *Gelidium glandulaefolium*, *Curdlea gymnogongroides* and *Zonaria sinclairii*. Lower down in the zone, particularly on steep faces, *Plocamium angustum*, *Rhodymenia australis* and *Pterocladia lucida* may occur in addition to the prominent species of this level referred to previously.

Mid Sublittoral Zone (5-15 (-19) m deep)

The upper boundary of the zone is sharply defined by the appearance of the laminarian *Ecklonia radiata* which dominates the zone and extends even into the lower sublittoral. *Ecklonia* is co-dominant with *Melanthalia* spp. and other brown algae at upper levels of the mid sublittoral where they form a dense canopy. (See *Ecklonia-Melanthalia* Community where the species are listed). Where agitation of the water is most severe, the undergrowth is sparse and in many places the rock is covered with a crust of lithothamnium.

Below about 10 m some minor changes in the vegetation occur. Brown algae (except *Ecklonia*) become sparse and a red algal undergrowth occurs under the canopy of *Ecklonia*. Toward the lower limit of the zone, *Ecklonia* becomes scattered and the red algal element increases.

There are no noticeable qualitative differences between the vegetation on vertical and on horizontal surfaces where the surge is active, i.e. to about 10 m depth on the rough shore (A), decreasing to about 1 m in the sheltered parts of Region B. However upper-storey species (mainly brown algae) are less prominent while under-storey species are more conspicuous on vertical than on level surfaces. With increasing depth (over 10 m) brown algae disappear rapidly from vertical faces and a red algal community is established, usually epizoid on a ground community of calcareous bryozoans (mainly Reteporidae). Some algae appear restricted to or have a strong preference for vertical faces. These are *Cheilosporum elegans*, *Epiphloea bullosa*, *Thamnoclonium dichotomum*, *Laurencia clavata*, *L. elata* and *L. filiformis*.

Lower Sublittoral Zone (17-29 m deep)

The occurrence of a uniform red algal community in this zone is discussed in detail later. Red algae form a dense cover on upward facing rocks but on steep slopes are sparse (Figure 11). Here the tough and wiry algae of shallow water are replaced by delicate, filamentous or flabellate species. Near the base of the island at 25-28 m, algae are sparse and the rock face is covered by sessile fauna. Large sponges, the ascidians *Herdmania momus* (Savigny) var. *granulifera* Heller and *Styela etheridgei* Herdman are prominent. Bryozoan colonies of *Retepora* spp. and *Adcona grisea* Lamouroux are abundant in places and provide a substrate for some algae e.g. *Thamnoclonium dichotomum* and *Plocamium* spp. Less prominent but quite common are stands of the hydroids *Plumularia procumbens* Spencer, *Sertularella lata* Bale and occasionally *Thecocarpacea ditarsicatus* Bale; orange and white gorgonians, crinoids and crustacea are abundant.

(II). REGIONS B AND C (MODERATELY ROUGH WATER)

These are regions of constant surge but lack the extremely rough conditions of the southern and western shores. Toad Head and Restless Point are the natural outer boundaries of the two regions as they mark the transition in the mid sublittoral from communities of few species dominated by *Ecklonia* to those in which there is a more varied brown algal vegetation. *Cystophora intermedia* disappears from the sublittoral fringe at about these points and is generally absent in regions B and C. Communities of green algae are common in more sheltered parts.

At the inner boundaries respectively (Point Gillian and Penguin Rock) the wealth of algae decreases markedly. Due to the shallower depths in the two regions a lower sublittoral zone is generally absent.

Upper Sublittoral Zone

From Toad Head northwards towards Penguin Rock the upper sublittoral decreases from 3 m broad to less than 1 m; it is occupied by a short and dense algal turf with often a thin encrusting sponge as a basal matrix. *Ulva lactuca* is often common at the upper limit of the zone. In the rougher parts of the regions, the algal turf comprises a *Corallina-Zonaria* community towards its lower limit, or further up on vertical faces the following species are frequently seen: *Halopteris funicularis*, *H. gracilescens*, *Lobospira bicuspidata*, *Areschougia laurencia*, *Ballia callitricha* (stunted).

The lower limit of the zone is often not clearly defined and some species more characteristic of the mid sublittoral may occur, e.g. *Cystophora moniliformis*, *C. subfarcinata*, *Scytothalia dorycarpa*, *Seirococcus axillaris*, *Sargassum verruculosum*, *Plocamium costatum*.

In more sheltered parts of the regions, the zone bears a *Pterocladia capillacea* association descending for about 1 m until it merges with the vegetation of the mid sublittoral zone. However, an *Amphiroa-Corallina* association is able to displace the mat of *Pterocladia* in a sunny aspect and in well-agitated water, in places, it dominates the slope from low water level to about 4 m deep.

Three communities of green algae are often seen. Between 1 and 2 m depth *Caulerpa brownii* occurs either as a monospecific community on horizontal rock surfaces or among the *Amphiroa-Corallina* community at the same depth. A little deeper between 2 and 4 m a *Caulerpa flexilis* community is common on horizontal rock faces. Occasionally a *Caulerpa obscura* community occurs at about 3 to 4 m.

Mid Sublittoral Zone

In the upper part of the zone, a fucoid association forms a dense cover over the rocks. The preference of algae for upward facing rocks with increasing depth has been described and is evident in this zone. The vegetation near the sublittoral base of the island is poor and limited to a few species of which the brown alga *Glossophora nigricans* is prominent. The poverty of algal growth is probably due to the presence of fine sediments on the rocks as is indicated by the common occurrence of the bulky ascidians *Herdmania momus* var. *grandis* and *Ascidia sydneyensis* Stimpson.

(III). REGION D (ABALONE COVE)

The depth of water is limited to 5 m and there is a general decrease in the number of species compared to other regions; the lower sublittoral zone is not present.

Upper Sublittoral Zone

This is very narrow (0.0-5 m) and is represented only by a dense mat of *Pterocladia capillacea*. At the boundaries of region D, where wave-action increases slightly, corallines are more in evidence and tend to displace the *Pterocladia* mat.

Mid Sublittoral Zone

Part of this area has a solid granite substrate and the remainder has a loose boulder slope with rounded stones up to 50 cm across. The vegetation varies according to the type of bottom. Small stones are unstable and do not support large brown algae. The solid rock bears a "forest" of *Ecklonia* (up to 80 cm high) with very few undergrowth species except for a thin crust of lithothamnium. Steep or vertical slopes, however, have small numbers of the following species: *Halopteris funicularis*, *H. gracilescens*, *H. pseudospicata*, *Dictyota diemensis*, *Zonaria angustata*, *Z. crenata*, *Z. spiralis*, *Sargassum verruculosum*, *Cheilosporum elegans*. These species are also common on all except the smallest stones of the boulder slope. The bright orange jointed bryozoan *Catenicella margaritacea* Busk is also conspicuous in this zone.

At about 3 m depth *Ecklonia* is largely replaced by species common in the fucoid association, namely—*Acrocarpia paniculata*, *Cystophora monilifera*, *C. moniliformis*, *C. subfarcinata* and the coralline algae *Cheilosporum elegans* and *Metagoniolithon charoides*. Nearby, the sandy bottom supports dense beds of the marine angiosperms *Amphibolis antarctica*, *A. griffithii*, *Posidonia australis* (narrow leaf form) and *Heterozostera tasmanica*. These sea-grass communities have not been studied in detail.

(IV). ALGAL ASSOCIATIONS AND COMMUNITIES

The associations and communities recognised about the island are described below. Communities of the eulittoral zone were not specifically studied and are only discussed where they extend into the sublittoral.

A list of the commoner algae, from the four regions recognised and with known depth ranges, is given in the Appendix.

1. CORALLINE ASSOCIATION

Many corallines tolerate strong light and occur commonly in the lower eulittoral and upper sublittoral. At West Island corallines are not prominent on the steeply sloping and shaded southern and eastern shores but are common elsewhere.

(a) *Corallina* community

Corallina sp.

Conditions:—Moderate to strong turbulence.

Vertical Range:—Lower eulittoral down to 1 m.

The community is well developed along the western shore of Region A, especially on horizontal or gently sloping rocks. The association with the barnacle *Balanus nigrescens* and certain molluscs has already been described (p. 114). This community extends into the lower eulittoral where *Balanus* may become dominant in some localities (as also described for Point Sinclair, Eyre Pen. (Womersley and Edmonds 1958)). In very rough conditions the community appears as short tufted groups of plants scarcely 5 cm high, but in more sheltered places plants are denser and may show a vivid pink growth to about 7-8 cm in height.

(b) *Amphiroa-Corallina Community*

Common:—*Amphiroa anceps*, *Corallina cuvieri*, *Cheilosporum elegans*.
Occasional:—*Corallina* sp.

Conditions:—Moderate turbulence.

Vertical Range: 0-5 m.

This community is prominent in Region C and portion of Region D near Penguin Rock and in optimal conditions forms a very dense turf to about 10 cm in height. Toward its lower limit, calcareous algal fragments accumulate among the living plants providing a haven for worms, crustaceans and molluscs. The proportions in which the component species occur may vary with depth as shown in Figure 13. Between 3 and 4 m, *Cheilosporum elegans* characteristically forms a pure stand on steep or vertical faces. Other species such as *Caulerpa brownii*, *Pterocladia lucida* and *Melanthalia obtusata* occasionally occur. This community is seen in similar habitats along much of the central Flindersian province of southern Australia.

(c) *Corallina-Zonaria Community*

Common:—*Zonaria sinclairii*, *Corallina cuvieri*. Fairly common:—*Sargassum bracteolosum*, *Cheilosporum elegans*. Occasional:—*Caulerpa brownii*.

Conditions:—Moderate turbulence.

Vertical Range: 0-3 m deep.

The community is well developed in moderately rough situations. It constitutes the uppermost sublittoral zone in Region B and also may be found in small stands in Region C. The development of *Sargassum bracteolosum* is seasonal: from February to September only the basal leaves are seen and the community is dominated by *Corallina cuvieri* and *Zonaria sinclairii* which forms a dense mat between 5 and 10 cm in height. In spring, *Sargassum bracteolosum* rapidly develops fertile fronds reaching 30 cm or more, then overshadowing the other components; these fertile fronds are completely lost again by February.

With increasing turbulence, *Corallina cuvieri* and *Sargassum bracteolosum* become sparse so that in some places there is an almost pure community of *Zonaria sinclairii*. This is seen mostly on gently sloping rock where the water is well agitated, and the community may continue into the lower eulittoral. The following species are more commonly seen on steep faces or toward the lower limit of the community—*Halopteris gracilescens*, *H. funicularis*, *Lobospira bicuspidata*, *Cheilosporum elegans*, *Areschougia dumosa*. It is uncertain whether their preference for a steep surface is due to a lower light requirement, a lower tolerance of surge, or both.

2. *PTEROCLADIA CAPILLACEA ASSOCIATION*

Common:—*Pterocladia capillacea*. Fairly common:—*Sargassum bracteolosum*, *Asparagopsis armata*, *Plocamium angustum*.

A number of other species occur but these are probably the outliers of communities lower down in the sublittoral. The following have been recorded at various times but are usually stunted in form and not common.

Caulerpa flexilis, *C. obscura*, *Dictyota diemensis*, *Zonaria sinclairii*, *Z. spiralis*, *Cystophora subfarinata*, *Corallina cuvieri*, *Melanthalia obtusata*, *Laurencia elata*.

Conditions:—Slight to moderate surge, with a preference for steep or vertical faces. Where the surge is more severe the association is displaced by corallines.

Vertical range: 0-2 m.

In Region D the association forms a dense turf between 5 and 10 cm high, down to about 1 m depth where it gives way to the laminarian *Ecklonia*. In Judith Cove (Region C) it may extend down to about 2 m where it is replaced by various brown algae. At very low tide the upper part of the association is just emergent and in the summer the upper plants are often bleached by the sun. *Corallina* sp. occurs occasionally and *Asparagopsis armata* is often epiphytic on the *Pterocladia*. The community has only occasionally been noted elsewhere in South Australia in similar conditions.

3. *GELIDIUM GLANDULAEFOLIUM*-*CURDIEA GYMNOGONGROIDES* ASSOCIATION

Common:—*Gelidium glandulaefolium*, *Curdiea gymnogongroides*. Fairly common:—*Melanthalia concinna*, *M. obtusata*. Occasional:—*Zonaria sinclairii*, *Polyopes constrictus*.

Conditions:—Extreme turbulence on steep faces.

Vertical Range:—from 1 to 3 m below low water.

This association is present at Lands End below the Coralline Association. It is most evident on steep or vertical rock faces, with the common species growing up to about 8 cm high. It forms a community with the barnacle *Balanus nigrescens* and the stalked ascidian *Pyura pachydermatina* var. *gibbosa*.

Occasionally, a mixed *Corallina*-*Gelidium* community is seen in places where the surge is strong but not severe. With increasing depth, the association becomes subordinate to the brown algae *Ecklonia* and *Scytothalia*.

4. FUCOID ASSOCIATION

Common:—*Acrocarpia paniculata*, *Cystophora monilifera*, *C. moniliformis*, *C. platylobium*, *C. subfarcinata*, *Seirococcus axillaris*, *Asparagopsis armata*. Fairly common:—*Scytothalia dorycarpa*. Occasional:—*Perithalia caudata*, *Ecklonia radiata*, *Sargassum bracteolosum*.

Conditions:—Moderate surge.

Vertical Range: 3-18 m deep (in calmer situations 1-10 m deep).

A dense vegetation of fucoid algae is a characteristic feature of rocky substrates on moderately rough shores of southern Australia; this community occurs throughout Regions B and C, and on some coasts in South Australia reaches to low tide level.

The structure of the association is complex; its vegetation is usually two-layered, but occasionally three-layered. The dense upper layer, ranging from 50 cm to 1 m in height, is dominated by fucoids, the individual species of which may occur in stands up to 10 m² in area, or sometimes as single or small groups of plants. The dissected and irregular nature of the rock surface on which the vegetation occurs creates numerous microhabitats with differing light and surge, resulting in a complex mosaic. Different species tend to be dominant at different depths. Figure 10 shows the vertical range of some species in Region B.

Ecklonia radiata is surprisingly sparse, being absent from most level surfaces but present on steep faces just below the lip of flat-topped rocks. In deeper water of 18 to 20 m, *Ecklonia* persists in a predominantly red algal community.

The middle layer is less complex; its height is from 10 to 20 cm and individual plants generally lie scattered and hidden under the shade of the prominent fucoid algae. At 5 m the undergrowth is mostly *Cheilosporum elegans*; at 8 m, *Zonaria* spp., *Corallina cuvieri*, *Halopteris* spp., *Plocamium angustum* and *Phacelocarpus labillardieri* occur. Between 10 m and 18 m the following species comprise the undergrowth: *Lobospora licuspidata*, *Zonaria spiralis*, *Asparagopsis*

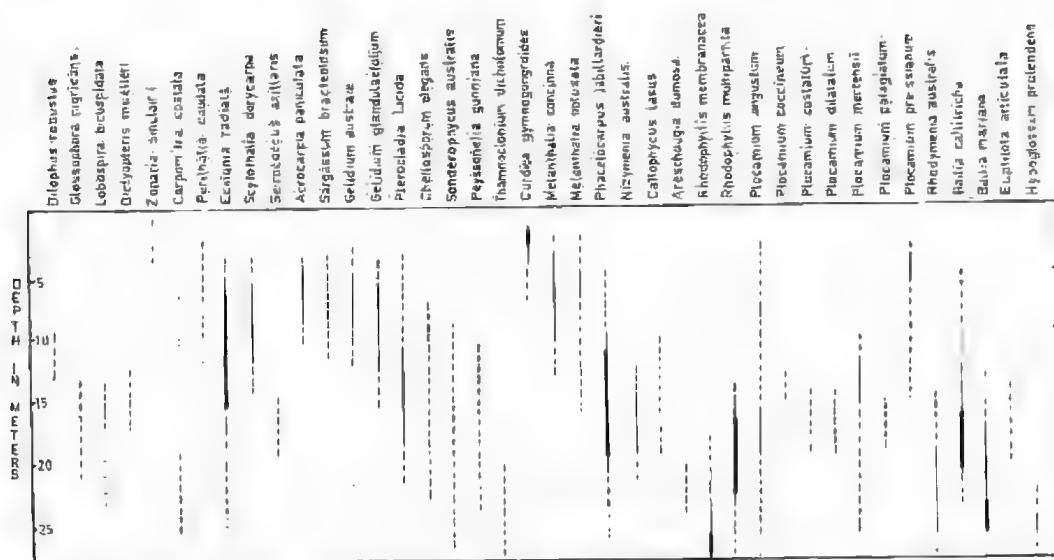


Fig. 8 Vertical range of some common algae on horizontal rock in Region A (rough). ——— common (shown by a thicker line where dominant); - - - - - occasional; + + + + + rare.

armata, *Peyssonelia gunniana*, *Phacelocarpus labillardieri*, *Plocamium angustum*, *P. mertensii*, *Rhodophyllis multipartita*, *Areschougia dumosa*, *Mychodia hamata* and *Osmundaria prolifera*.

At 18-20 m deep, the upper layer comprises mainly *Ecklonia* and *Cystophora platylobium* and is much less dense than in shallower water. On many slopes stands of *Plocamium* spp. are well developed. Here also a ground layer of prostrate species occurs, e.g. *Peyssonelia gunniana*, *P. novae-hollandiae* and *Sonderopycus australis*.

With increasing shelter there are minor changes in the association. Some species become more common, e.g. *Sargassum verruculosum*, *Corallina* sp., *Metagoniolithon charoides* and *Metamastophora flabellata*. Figure 15 shows the horizontal distribution of some of these species.

In Region C where similar surge conditions exist, the vegetation patterns typical of the upper part of the association in Region B are seen. The undergrowth species are mainly *Metamastophora flabellata*, *Metagoniolithon charoides*, *Cheilosporum elegans* and *Corallina* sp.

Floristically, the association is very rich and the total number of species collected is about 80.

5. ECKLONIA RADIATA ASSOCIATION

Ecklonia radiata is one of the most important and conspicuous zone-forming species of algae of southern Australia. It is prominent at West Island where it dominates two habitats on the rough and sheltered sides of the island respectively. In each habitat, *Ecklonia* constitutes the bulk of the vegetation (Figures 9, 14). In Region A, it characterises a community in water 3 to 18 m deep and in the sheltered Region D it occurs from about low water down to 5 m. Each community will be discussed in turn.

Why *Ecklonia* is not more common on the moderately rough shores of Region B is puzzling. It is possible that this laminarian may be unable to compete well with fucoid algae where conditions are optimal for their development.

Ecklonia—*Melanthalia* community

Common:—*Ecklonia radiata*, *Scytothalia dorycarpa*, *Melanthalia concinna*. Fairly common:—*Acrocarpia paniculata*, *Sargassum bracteolosum*, *Melanthalia obtusata*. Occasional:—*Seirococcus axillaris*, *Perithalia caudata*.

Undergrowth—Common:—*Gelidium glandulaefolium*. Fairly common:—*Pterocladia lucida*, *Phacelocarpus labillardieri*, *Plocamium preissianum*. Occasional:—*Zonaria sinclairii*, *Corallina* sp., *Polypes constrictus*, *Callophycus laxus*, *Ballia callitricha*.

Conditions:—Strong to extreme surge.

Vertical Range:—4-10 (-14) m deep.

The species listed are all able to stand extreme water movement. The structure of the community is two-layered. The upper layer consists of *Ecklonia*, *Scytothalia*, *Seirococcus* and *Acrocarpia*. Under these plants, an understorey of algae growing to about 20 cm in height occurs. The turbulence is too great for most animals except *Pyura pachydermatina* var. *gibbosa* and compound ascidians which colonise steep faces. The vertical ranges of the algae are shown in Figure 8.

Ecklonia community

Ecklonia radiata and encrusting lithothamnium.

Conditions:—Slight continuous surge.

Vertical Range:—0-4 m deep.

Very dense stands of *Ecklonia* occur on firm granite substrate. Undergrowth species are absent except for the presence of pink encrusting lithothamnium on the rock.

Both *Ecklonia* and the lithothamnium prefer well-agitated and sediment-free water and conditions are no doubt favourable where the swell passing around each side of the island causes intersecting wave patterns and a consequent continual water movement (Figure 4).

6. OSMUNDARIA PROLIFERA ASSOCIATION

Common:—*Osmundaria prolifera*. Fairly common:—*Cystophora monilifera*.

Conditions:—Moderate surge.

Vertical Range:—3-8 m deep.

Although this association is relatively common in deeper sheltered waters of St. Vincent Gulf, it is poorly developed at West Island and occurs in only a few places in the more sheltered parts of Region B. The association has a simple structure and is dominated by *Osmundaria prolifera* with *Cystophora monilifera* as a characteristic associated species.

7. RED ALGAE ASSOCIATION

Common:—*Nizymenia australis*, *Rhodophyllis membranacea*, *R. multipartita*, *Plocamium angustum*, *P. mertensii*, *Rhodymenia australis*, *Ballia mariana*. Fairly common:—*Sonderophycus australis*. Occasional:—*Gelidium australe*, *Pterocladia lucida*, *Peyssonelia gunniana*, *Thamnoclonium dichotomum*, *Areschougia dumosa*, *Ballia callitricha*, *Haloplegma preissii*, *Hypoglossum protendens*. Rare:—*Cheilosporum elegans*, *Phacelocarpus labillardieri*, *Osmundaria prolifera*.

Conditions:—Reduced light and slight surge.

Vertical Distribution:—16-28 m deep on horizontal and sloping rock, occasionally shallower (see below).

This association is developed in the deeper, quieter waters about the island, i.e. in Region A and the outer part of Region B. The brown algae of the mid sublittoral gradually disappear between 10 and 15 m depth and are replaced by this community. However, *Ecklonia* may persist sporadically down to 24 m or more (Figures 7, 8, 14).

In shaded aspects and in calmer microhabitats such as depressions in the rock, the association occurs at levels up to 10 m but is best developed between 15 and 20 m deep. The association is floristically rich with 48 species recorded; plant cover is almost 100% with a two-layered structure. Some algae are commonly up to 30 cm high and there is in places a low ground layer of prostrate species—*Sonderophycus australis*, *Peyssonelia gunniana* and *P. novae-hollandiae*.

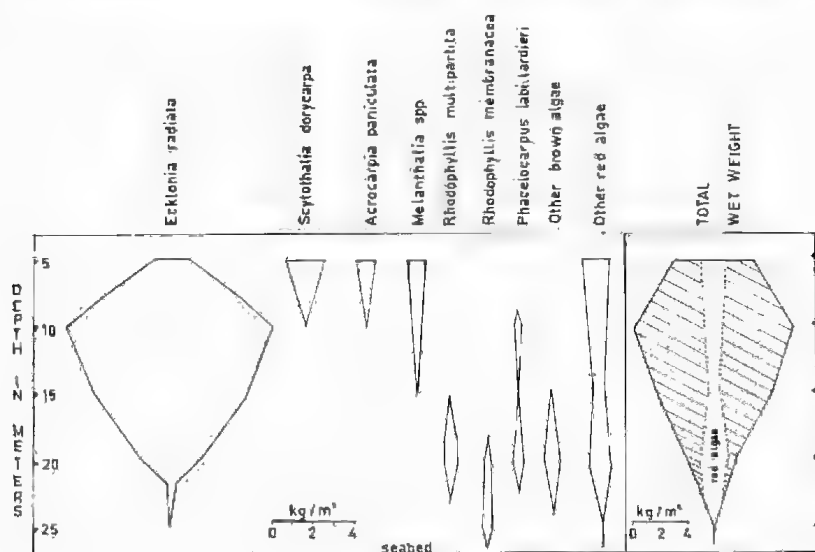


Fig. 9 Vertical distribution of wet weight of algae on horizontal surfaces between 5 and 27 m deep near Seal Rock in Region A (rough). The broken line indicates total weight of red algae.

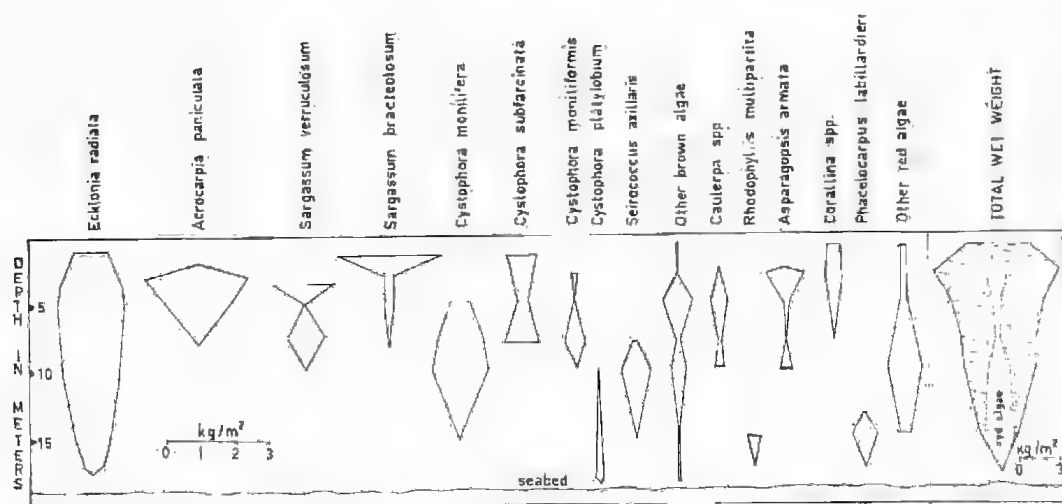


Fig. 10 Vertical distribution of wet weight of algae on horizontal surfaces between 2 and 18 m deep in Region B (moderately rough). The broken line indicates total weight of red algae.

Individual species of the upper layer may occur from single plants to patches up to 1 square meter in area. It is uncertain whether the observed patchiness is chance or is caused by ecological factors. Bergquist (1960a) comments on the same feature in New Zealand waters.

In deeper water (over 20-22 m), plant cover decreases to less than 10% as the fauna becomes dominant and covers the rock face. Frequently, algae in this region are attached to bryozoa. The number of species also declines and at 25 m only 15 species were recorded. At this depth red algae grow only on the upper faces of rocks, the steep faces of which are covered entirely by sponges, gorgonia, corals, bryozoa and hydroids. Some algal species become heavily epiphytised by bryozoans, hydroids and sponges. Changes in the composition of the association with depth are shown in Figures 8, 9 and 11.

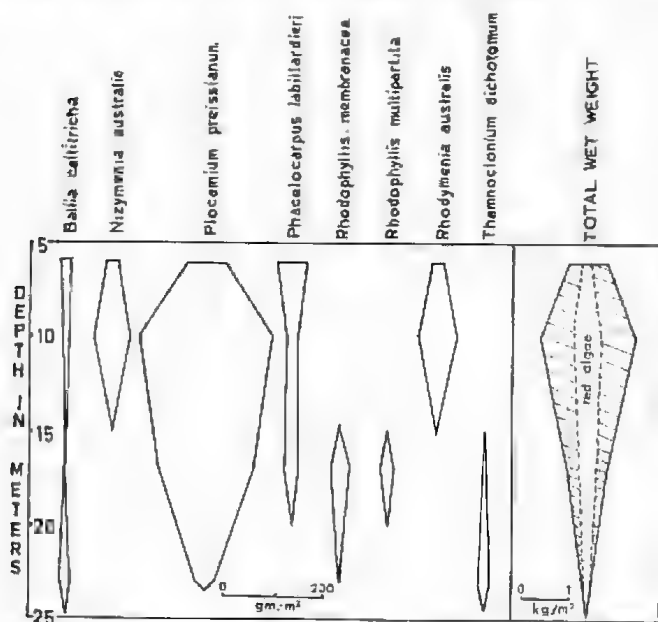


Fig. 11 Vertical distribution of wet weight of algae on vertical rock faces between 6 and 25 m deep at Seal Rock in Region A (rough). The shaded area represents total wet weight of *Ecklonia radiata*, which is not given as a separate diagram.

8. CAULERPA COMMUNITIES

Several species of *Caulerpa* are of common occurrence about the island. As their fronds rise from creeping stolons often densely intertwined, communities which occur in favourable conditions spread over extensive areas. Except where surge is strong, particulate matter accumulates among the stolons and probably prevents establishment of other algae. These communities are well developed on upper surfaces of rocks in agitated shallow water with maximal light conditions and are not uncommon in similar habitats elsewhere on the southern Australian coast.

Caulerpa brownii community

Conditions:—Moderate surge.

Vertical Range:—Usually 1 to 1.5 m deep. Scattered plants as deep as 5 m.

The species forms a dense community of plants up to 10 cm in height, in Regions B and C, usually on upward facing rocks. Sometimes scattered plants of *Sargassum bracteolosum* and *Perithalia caudata* occur where the association is not dense. *C. brownii* is also common in the lower eulittoral algal mat in Regions B and C.

Caulerpa flexilis community

Conditions:—Moderate surge.

Vertical Range:—2.5 m deep.

The stolons form a dense basal mat sheltering a rich crustacean, molluscan and worm fauna. Above it the fronds form a dense cover to about 15 cm in height. At West Island the community prefers slightly deeper water than *Caulerpa brownii* and is found in Regions B, C and D.

Caulerpa obscura community

Conditions:—Moderate surge.

Vertical Range:—5.7 m deep.

This community is common on horizontal or sloping rocks in Region B in rather deeper water than either of the other *Caulerpa* communities. The fronds are up to 20 cm long and are a haven for very large numbers of amphipods and isopods.

SEASONAL AND OTHER CHANGES

Nearly all the prominent algal species (see Appendix) are present throughout the year, though some show pronounced seasonal growth. However data on many of the smaller species are not adequate to judge whether some might be strictly seasonal in occurrence. Many red algae also appear to live for up to two years and show at least two age groups; younger plants are relatively free from epiphytes such as hydroids and certain bryozoans whereas older plants are often heavily epiphytised.

Algal growth is vigorous from winter until early summer. By midsummer the vegetation has an impoverished appearance as many species shed their fertile parts. The following changes are conspicuous; *Scytothalia dorycarpa* and *Scirococcus uxillaris* lose some fronds and receptacles; *Cystophora moniliformis* loses its ramuli, leaving only the bare primary and secondary axes; the fronds of *Caulerpa flexilis* and *C. brownii* disappear leaving only their stolons on the rock face; the corallines lose fronds and ramuli often leaving bare stalks. During March, strong growth commences and the vegetation soon regains its winter appearance. As previously described, *Sargassum bracteolosum* grows seasonally during spring and sheds its fertile fronds by late summer (February). The growth of *Ecklonia* appears to cease during mid-summer and at this time the plants often lose part of their thalli while the remainder is often grazed by the gastropod *Subnirrella undulata* (Solander).

After completion of the main part of this study some changes in the vegetation were noticed during the summer of 1969-70. The density of *Ecklonia* greatly increased on the boulder slope in Region D, where it had previously been sparse, and at a depth of 4 to 5 m *Cystophora monilifera*, which previously had occurred as scattered plants, formed dense stands over one metre in height. The understorey species of smaller brown algae largely disappeared from this canopied area and were replaced by a low mat of *Corallina cuvieri* and *Corallina* sp. The brown alga *Cladostephus verticillatus* was noticed for the first time and became abundant in places. The winter of 1969 was free of storms and these changes are probably attributable to the calm conditions which had prevailed since the winter of 1968.

Changes such as these will be followed over the next few years in order to judge the stability of the associations described in this paper.

ESTIMATES OF STANDING CROP

In order to assess the individual contribution of species to the total biota, a quantitative study was made at selected localities on both horizontal and vertical faces. Over 100 samples were collected between August and December in 1967 and in 1968 by using a hoop of area $1/6 \text{ m}^2$ on horizontal surfaces and $1/10 \text{ m}^2$ on vertical faces. The hoop was placed on a rock and the algae were scraped from within the area into a net and later examined and weighed. Because of the physical difficulty in obtaining samples in strong surge where 10 minutes might be occupied for each, random sampling techniques were not feasible and the following procedure was adopted. A visual assessment was first made of the locality to select a rock face on which the algae were considered to be representative of the average density and cover for that locality. Any rock face which appeared to be either unusually protected or subjected to extreme water movement was therefore avoided. A number of contiguous samples was then scraped from the rock over a horizontal distance of several metres. This was repeated at various depths and localities. On vertical cliff faces a site facing the direction of the swell was selected in each case to minimise local effects.

At any single locality, 5 or 6 samples were considered sufficient to adequately sample the fairly uniform red algal growth (although often more were taken), but for the patchily occurring larger brown algae a more extensive area was sampled and a proportion of the plants collected. The method used by Crossett and Larkum (1966) is very similar. The results are given in Figures 9-14. At Seal Rock and at Toad Head samples were taken at approximately 3 metre intervals vertically, and in Judith Cove at one metre intervals.

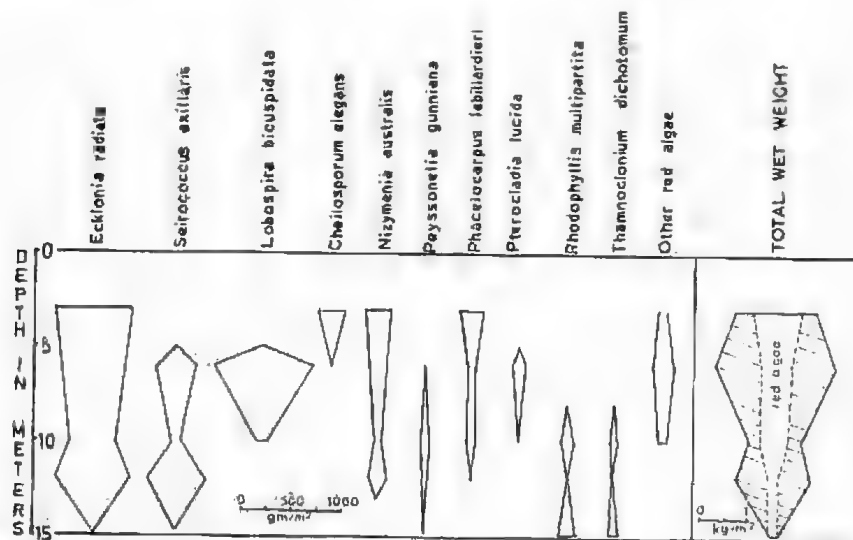


Fig. 12 Vertical distribution of wet weight of algae on vertical rock faces between 3 and 15 m deep in Region B (moderately rough). The shaded area represents total wet weight of brown algae.

Since *Ecklonia* dominates the vegetation in the mid sublittoral in Regions A and D, estimates of density (number of plants per m^2) and cover were also obtained. The results (Figure 14) show that the population density of *Ecklonia* is greatest ($20+$ plants per m^2) at a depth of 6 m in rough conditions (Region

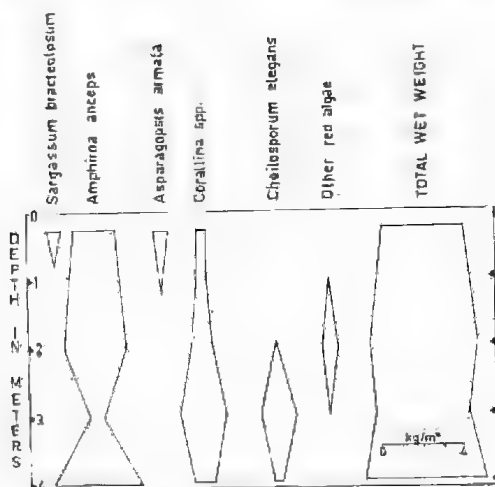


Fig. 13 Vertical distribution of wet weight of algae in *Amphiroa-Corallina* association in Region C.

A) and at 2-4 m depth in Region D. In Region B the highest density values are at a depth of 4-5 m but are much lower (5 plants per m^2), probably due to competition from other species.

However, Figure 9 shows that the highest standing crop values (fresh weight) in Region A for *Ecklonia* occur at a depth of 10m, i.e., somewhat deeper than the depth at which the highest density values occur. This is because the size and weight of individual plants in very rough conditions (i.e. Region A, 5-8 m) is much less than in conditions where surge is moderate (the figures for mean plant weight being 95 g for the former conditions as compared to 600-800 g for less rough waters according to locality). Plants constantly subject to severe surge rarely develop to the size of those under less extreme conditions, and stipes with tattered or missing thalli are commonly seen after stormy weather.

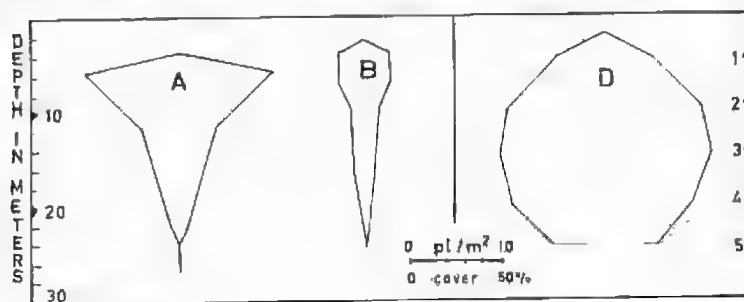


Fig. 14 Vertical distribution of plant density (as number of plants per square metre) of *Ecklonia radiata* on horizontal surfaces in Regions A, B and D.

DISCUSSION

The decrease in surge from rough to sheltered shores of the island is accompanied by conspicuous differences in the composition of the vegetation. The distribution of each species depends upon its particular response to and tolerance of various environmental factors. The survey has shown that groups of species have similar distribution patterns resulting in the occurrence of plant communities which persist throughout an area so long as the environment remains substantially unchanged. The same communities are seen in other places where a similar environment recurs. At several points abrupt changes in the type of community are also accompanied by a relatively steep gradient in surge or illumination, these being probably the two most important environmental factors.

TABLE 4

Showing the total number of species found in the various regions.

U.S.L. — Upper Sublittoral; M.S.L. — Mid Sublittoral; L.S.L. — Lower Sublittoral.

	Green Algae				Brown Algae				Red Algae				Total of all Species
	U.S.L.	M.S.L.	L.S.L.	Total	U.S.L.	M.S.L.	L.S.L.	Total	U.S.L.	M.S.L.	L.S.L.	Total	
Rough Region A	1	—	1	2	3	6	3	9	6	25	48	65	76
Moderately Rough Region B	2	7	—	7	3	24	—	24	2	60	—	61	92
Moderately Rough Region C	1	5	—	5	2	12	—	12	5	10	—	12	29
Semi-Sheltered Region D	1	5	—	5	1	16	—	16	4	5	—	6	27
Total Number of Species				9				30				93	132

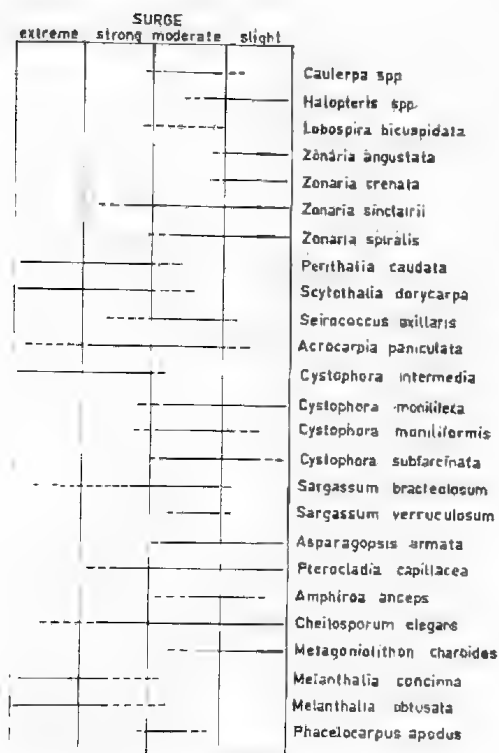


Fig. 15 Horizontal range of common algae of the mid-sublittoral. Extreme to strong surge—Region A. Moderate surge—Regions B and C. Slight surge—Region D.

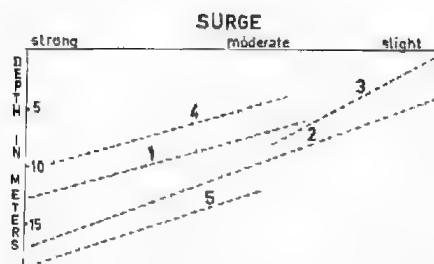


Fig. 16 Elevation of the upper limits for some species with reduction in surge.

1. *Lobospora bicuspidata*, *Seirococcus axillaris*, *Nizymenia australis*, *Rhodophyllis multipartita*, *R. membranacea*.
2. *Mychodea hamata*, *Osmundaria prolifera*, *Laurencia clavata*.
3. *Zonaria angustata*, *Zonaria spiralis*, *Asparagopsis armata*.
4. *Metamastophora flabellata*, *Cheilosporum elegans*, *Euptilota articulata*.
5. *Thamnoclonium dichotomum*.

A feature of the survey is that comparatively few species comprise the bulk of the vegetation while many species occur in small numbers or in a restricted locality.

Horizontal Distribution

The total number of species in the four regions varies considerably and their distribution in regions and zones is given in Table 4. It is apparent that a shore of moderate roughness favours the greatest number of species; this is due to the occurrence of two floristically rich communities viz. the Fucoid Association in the mid sublittoral and the lower sublittoral association of red algae. However, the latter association is better developed in the deeper waters of Region A where there is lower light intensity.

Figure 15 gives the horizontal ranges of some common species, mostly of the mid sublittoral, and it is evident that water movement is an important factor limiting the horizontal distribution of most algae to that part of the shore where suitable conditions exist. Some shade-tolerant species (see Figure 16) are able to extend their horizontal range by growing at a greater depth in rougher conditions.

Green algal (*Caulerpa*) communities require rather sheltered conditions and are distributed accordingly. Their occurrence at different depths probably reflects their particular requirements for light rather than for water movement.

Vertical Distribution

It must be re-emphasized here that this survey deals with the algae of horizontal and vertical or steeply sloping rock surfaces on a "steeply sloping" granitic island. These habitats are relatively uniform compared to those on calcareous coasts where rock platforms at about low tide level offer a great variety of pools and overhangs giving great diversity in microhabitat conditions of light and water movement. On such rock platforms (see Womersley 1948), many species recorded only from deeper zones (e.g. the mid sublittoral) on West Island are found in shaded or sheltered pool areas. At low tide, deep pools on rock platforms provide conditions of surge comparable to those at some depth.

Changes in algal vegetation with depth have been documented for many seas (for recent studies see Crossett and Larkum 1966, Jorde 1966, Kitching 1941, Neushul 1965, Petrov 1967, Vozzhinskaya 1965, and Zaneveld 1966). Other workers have shown experimentally that important controlling factors are gradients in light and water movement (see Conover 1968, Feldmann 1937, Jorde and Klavestad 1963, Levring 1947, 1966, 1968, Whitford and Kim 1966). These factors will now be discussed for each zone.

(1) Upper Sublittoral Zone

This zone, best developed in Region A, is dependent on rough conditions (Figure 6). Some species (*Cordia gymnogongroides*, *Melanthalia* spp. and *Polyopes constrictus*) require high water movement and are restricted to this zone; others tolerate these conditions and range more widely in the sublittoral (e.g. *Gelidium glandulaefolium*, *Pterocladia capillacea* and *Corallina* spp.). Strong light is a limiting factor for many species, but some brown algae (*Sargassum bracteolosum*, *Zonaria sinclairii*, *Cystophora subfarcinata* and *Acrocarpia paniculata*) and coralline algae (*Corallina* spp. and *Amphiroa anceps*) withstand full sunlight and even grow in momentarily emergent situations (see p. 118 and Figure 7). Feldmann (1951) attributes the success of corallines in high light intensities to the presence in their tissues of calcium carbonate which serves as a light shield. This probably explains their abundance in sunny aspects about the island.

In rough areas of West Island the upper limit of the upper sublittoral zone is marked by the sublittoral fringe zone of *Cystophora intermedia* (Womersley and Edmonds 1958, p. 233) as shown in Figure 7. This fringe zone is absent on less rough coasts (Regions B, C, D) where the mid sublittoral large brown algal associations approach closer to low tide level.

The lower limits of the upper sublittoral zone are often indicated by the tattered remnants of species characteristic of the zone below, suggesting that wave action prevents the encroachment of algae characterising the mid sublittoral by its destructive effect on these young plants, probably during storms, rather than by preventing their initial establishment.

(2) Mid-Sublittoral Zone

The importance of surge rather than light in determining the depth at which an algal zone occurs is strikingly shown for the mid sublittoral zone. As shown in Figure 6, this zone is depressed in rougher conditions. In such cases surge conditions are of primary importance providing light intensities are still adequate for the species concerned.

The most conspicuous alga of this zone, *Ecklonia*, grows to a considerably greater depth in Region A (Figures 9, 10 and 14) than in the other regions, and in other rough ocean areas of South Australia occurs at much greater depths (Shepherd, unpublished data). Other West Island species whose lower limit is similarly extended by greater water movement are *Perithalia caudata*, *Gelidium australe*, *G. glandulaefolium*, *Pterocladia lucida*, *Cheilosporum elegans*, *Thamnochlonium dichotomum* and *Nizymenia australis*.

On the other hand some species of algae do not grow at greater depth in rougher conditions (e.g. *Acrocarpia paniculata*, *Cystophora moniliformis*, *C. monilifera* and *C. subfarcinata*) and it is probable that light attenuation is the critical factor determining the lower limit for these species.

Asparagopsis armata occurs principally as an epiphyte, but shows little preference for a particular algal host (see Appendix). It is unable to grow in very rough conditions but is prolific elsewhere. At its lower limits the species appears to be sensitive to reduced water movement. On European coasts the species has a narrower vertical range but its ecology is otherwise similar (see Dizerbo 1964).

A third factor which may be important in limiting the growth of some algae at depth is the nature of the surface film on the substrate. It has been observed that some algae (e.g. *Ecklonia*, *Scytothalia* and *Scirococcus*) only grow on clean rock surfaces. In deeper water, with reduced water movement, the rock is covered with sediments of various kinds. Such a surface may be unsuitable for establishment of these algae. This factor is clearly related to water movement and further studies are necessary to elucidate it.

(3) Lower Sublittoral Zone

This zone is occupied by species which are adapted to low light conditions and slight surge. The decrease in light below 25 m, associated with turbidity near the bottom, is probably responsible for the disappearance of algae just below this depth. However, other factors not investigated may also have some effect; these include the deposition of sediment previously mentioned (see Strachan and Koski 1969) and the smothering effect of epiphytic bryozoans on some algae. The lower limit for attached algae for the waters of Encounter Bay is probably about 30 m; further offshore, in deeper waters, the lower limit is known to exceed 35 m.

The factors determining the upper limit for red algae are problematic and it is not often possible to distinguish between the effects of light and surge.

Rhodophyllis multipartita and *R. membranacea* appear to be sensitive to both factors and are appreciably displaced upwards only with a combination of sheltered and shaded conditions (Figures 9-12). Some species appear to respond in the same way to reduced water movement (see Figure 16). However, it appears that most species of the mid and lower sublittoral are sensitive to strong light to some degree. Uplift of limits in shade has been noted for *Thamnoclonium dichotomum*, *Pterocladia lucida*, *Metamastophora flabellata*, *Ballia mariana* and *B. callitricha*. The last named species has a remarkable vertical range and is able to grow in deep shade in the upper sublittoral in rough conditions.

Standing Crop and Density

The variation in standing crop values taken on horizontal and vertical surfaces (Figures 9-12) further illustrates the effects of light and water movement on algae.

On vertical surfaces where light intensity is 10-40% of that on horizontal surfaces at a given depth (Table 3) there is a substantial reduction in the total weight of standing crop. This is due partly to changes in community structure and partly to competition for space with faunal elements which predominantly colonise steep or vertical surfaces.

Comparison of standing crop values in Region A with those of Region B (Figures 9-12) shows that, except at upper levels (0-6 m, Region A) where mechanical damage by wave action is considerable, there are higher standing crop values on both horizontal and vertical surfaces in the rougher locality. This is probably due both to the better conditions for growth provided by increased water movement and to associated effects permitting greater density of algae, such as the presence of a cleaner substrate and the depression of certain faunal species into deeper water.

In Region A the highest standing crop values for *Ecklonia* are 10.4 kg/m² (at 10 m) and there are even higher values of 16.8 kg/m² in Region D at 3 m depth. These values are comparable with values for *Laminaria hyperborea* forests on coasts about the North Sea (e.g. 11.1 kg/m² reported by Luning 1969, and 6 kg/m², a mean of 59 surveys, found by Walker 1954),

Floristic Aspects

Further detailed collecting around West Island would doubtless considerably extend the total of 132 species of green, brown and red algae recorded in Table 4 (the commoner ones being listed in the Appendix). It is clear however that certain groups or genera are conspicuous in the sublittoral while others are notably absent.

In the Chlorophyta, only the genus *Caulerpa* is common (6 species and 3 recognised communities). In the Phaeophyta, the Dictyotales (especially species of *Zonaria*) and the Fucales are most conspicuous, though the only member of the Laminariales (*Ecklonia*) found on central South Australian coasts is ecologically important.

In the Rhodophyta, two genera of the Gigartinales are strikingly common, both in species and occurrence; these are *Plocamium* with 8 species and *Rhodophyllis* with four species. The Ceramiales are not widely represented compared to the large number of genera and species found in southern Australia; this applies especially to the family Rhodomelaceae. However, further collecting may well result in many additions of small species in this order.

With the exception of the coralline algae (which reach the lower eulittoral)

and some of the large brown algae which reach to low tide level, all the species recorded (see Appendix) are found only in the sublittoral. The general lack of algae above low tide level on South Australian coasts has been documented by Womersley and Edmonds (1958).

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APPENDIX. ALGAL SPECIES LIST

The following list includes the commoner species collected during the survey but not those found only rarely. Further collecting, especially in other micro-habitats than vertical and horizontal rock, would doubtless increase the number of species. Womersley 1956b and 1967 give references to the southern Australian species of Chlorophyta and Phaeophyta respectively, but no single reference to the species of Rhodophyta is currently available. Specimens representative of all species are deposited in the Algal Herbarium, Department of Botany, University of Adelaide.

The distribution of each species is given as in the four regions recognised (A, B, C, D), followed by the depth range in metres. References to text figures concerning the species are given where appropriate.

Most species are present throughout the year, although some show their best development in spring and summer.

CHLOROPHYTA

ULVALES

Ulva lactuca L. B, 0-1; C, 0-1; D, 0-1.

CAULERPALES

Caulerpa brownii (C. Ag.) Endl. A, 0-3; B, 0-2; C, 0-2; D, 0-2. (Fig. 15).

Caulerpa cactoides (Turner) C. Ag. B, 5.

Caulerpa flexilis Lamx. B, 2-5; C, 2-5; D, 3. (Fig. 15).

Caulerpa geminata Harvey. A, 5; B, 8; D, 1. (uncommon).

Caulerpa obscura Sonder. C, 3-7; D, 4-5. (Fig. 15).

Caulerpa scalpelliformis (R. Br.) C. Ag. D, 4. (uncommon).

CODIALES

Codium pomoides J. Ag. A, 10-15; D, 5-7. (uncommon).

PHAEOPHYTA

SPHACELARIALES—Stypocaulaceae.

Halopteris funicularis (Mont.) Sauv. B, 3-6; D, 1-5. (Fig. 15).

Halopteris gracilescens (J. Ag.) Womersley. B, 3-6; C, 3-6; D, 1-5. (Fig. 15).

Halopteris pseudospicata Sauv. D, 3-5. (Fig. 15).

Cladostephaceae

Cladostephus verticillatus (Lightf.) C. Ag. D, 3-4.

DICTYOTALES—Dictyoteae.

Dictyota diemensis Kuetzing (narrow form). C, 1-5; D, 3-5.

Dictyota prolifera Lamx. B, 15-22.

Dilophus robustus (J. Ag.) Womersley. A, 10-13; B, 16. (Fig. 8).

Glossophora nigricans (J. Ag.) Womersley. A, 16-18; B, 10-22. (Fig. 8).

Lobospira bicuspidata Aresch. A, 13-25; B, 6-25; D, 2-6. (Figs. 8, 12, 15, 16).
(commonly epiphytic on *Acrocarpia paniculata*, *Seirococcus axillaris* and *Phacelocarpus labillardieri*).

Pachydictyon paniculatum (J. Ag.) J. Ag. B, 3-6; D, 3-5.

Zonarieae

Dictyopteris muelleri (Sonder) Reinbold. A, 13-25; B, 16-26. (Fig. 8).

Zonaria angustata (Kuetz.) Pap. B, 13-22; D, 1-5. (Figs. 15, 16).

Zonaria crenata J. Ag. A, 22; D, 3-5. (Fig. 15).

Zonaria sinclairii H. & H. A, 0-5; B, 0-13; C, 0-5; D, 0-5. (Figs. 8, 15).

Zonaria spiralis (J. Ag.) Pap. A, 1-3; B, 10; D, 1-5. (Figs. 15, 16).

SPOROCHNALES

Carpomitra costata (Stackh.) Batters. A, 7-25; B, 13-22. (Fig. 8).

Perithalia caudata (Lab.) Womersley. A, 2-14; B, 5-10; C, 2-3. (Figs. 8, 15).

LAMINARIALES

Ecklonia radiata (C. Ag.) J. Ag. A, 4-22; B, 2-20; C, 1-5; D, 0-5. (Figs. 7-12, 14).

FUCALES—Seirococcaceae

Scytothalia dorycarpa (Turn.) Grev. A, 2-17; B, 10. (Figs. 7-9, 15).

Seirococcus axillaris (R. Br.) Grev. A, 14-20; B, 7-25; C, 4-5. (Figs. 8, 10, 12, 15, 16).

Cystoseiraceae

Acrocarpia paniculata (Turn.) Aresch. A, 3-11; B, 3-15; C, 3-5; D, 3-5. (Figs. 8, 9, 10, 15).

Cystophora intermedia J. Ag. A, sublittoral fringe. (Figs. 7, 15).

Cystophora monilifera J. Ag. B, 5-8; D, 1-5. (Figs. 10, 15).

Cystophora moniliformis (Esper) Wom. and Nizam. B, 1-9; C, 3-5; D, 1. (Figs. 10, 15).

Cystophora platylobium (Mert.) J. Ag. B, 10-18. (Fig. 10).

Cystophora subfarcinata (Mert.) J. Ag. B, 2-6; C, 3-5; D, 3-5. (Figs. 10, 15).

Sargassaceae

Sargassum bracteolosum J. Ag. A, 3-13; B, 0-10; C, 0-5; D, 0-2. (Figs. 10, 13, 15).

Sargassum verruculosum (Mert.) C. Ag. B, 4-16; D, 2-3. (Figs. 10, 15).

RHODOPHYTA

NEMALIONALES—Helminthocladiaceae

Liagora harveyiana Zeh. B, 3-6 (uncommon).

Bonnemaïsoniaceae

Asparagopsis armata Harvey. A, 16-25; B, 6-16; C, 3-5; D, 0-2. (Figs. 10, 13, 15, 16).

(A common epiphyte on *Zonaria* spp., *Acrocarpia paniculata*, *Cystophora monilifera*, *C. moniliformis*, *Sargassum verruculosum*, *Gelidium glandulaefolium*, *Pterocladia capillacea* and *Amphiroa anceps*).

- Delisea elegans* (C. Ag.) Mont. A, 16-19; B, 13-16.
Delisea hypneoides Harvey B, 13 (uncommon).
Delisea pulchra (Grev.) Mont. A, 19-22 (uncommon).
Leptophyllis conferta (R. Br.) J. Ag. B, 13-22.

GELIDIALES

- Gelidium australe* J. Ag. A, 3-23; B, 3-13. (Fig. 8).
Gelidium glandulaefolium H. & H. A, 4-20; B, 6-10. (Figs. 7, 8).
Pterocladia capillacea (Gmel.) Born. & Thur. B, 3-6; C, 0-5; D, 0-5. (Fig. 15).
Pterocladia lucida (R. Br.) J. Ag. A, 4-22; B, 6-10 (Figs. 8, 12).

CRYPTONEMIALES—Squamariaceae

- Peyssonelia gunniana* J. Ag. A, 11-24; B, 13-22. (Figs. 8, 12).
Peyssonelia novae-hollandiae (Kuetz.) Harvey. A, 12-22; B, 12-18.
Sonderophycus australis (Sonder) Denizot. A, 8-26; B, 13-22. (Fig. 8).

Corallinaceae

- Amphiroa anceps* (Lamarck) Denc. C, 2-5. (Figs. 13, 15).
Cheilosporum elegans (H. & H.) Aresch. A, 8-23; B, 3-16; C, 1-3; D, 3-5. (Figs. 8, 12, 13, 15, 16).
Corallina cuvieri Lamx. A, 0-2; B, 3-10; C, 2-5; D, 1-5. (Figs. 7, 10, 13).
Corallina sp. A, 0-3; B, 1-3; C, 1-5; D, 2-5. (Figs. 7, 10, 13).

The species of *Corallina* need detailed study; two taxa may be present under *C. cuvieri* and the status of *Corallina* sp., possibly related to *C. officinalis*, needs clarification.

- Metagoniolithon charoides* (Lamx.) W.v.Bosse. B, 2-6; D, 5. (Fig. 15).
Metamastophora flabellata (Sonder) Setchell. A, 10-18; B, 7-13. (Fig. 16).

Cryptonemiaceae

- Carpopeltis phyllophora* (H. & H.) Schmitz. A, 10-18; B, 6-13.
Epiphloea bullosa (Harv.) Schmitz? A, 10-16.
Polyopes constrictus (Turn.) J. Ag. A, 2-6; D, 0-2.
Thamnochlonium dichotomum (J. Ag.) J. Ag. A, 13-26; B, 10-13. (Figs. 8, 11, 12, 16).

GIGARTINALES—Gracilariaceae

- Curdiea gymnogongroides* J. Ag. A, 1-8; C, 2-3. (Figs. 7, 8).
Melanthalia concinna J. Ag. A, 3-10; B, 3-12. (Figs. 7, 8, 9, 15).
Melanthalia obtusata (Lab.) J. Ag. A, 6-16; B, 6-10; C, 1-2. (Figs. 7, 8, 9, 15).
 var. *intermedia* (Harv.) J. Ag. A, 16-18; B, 6-10.

Plocamiaceae

- Plocamium angustum* (J. Ag.) H. & H. A, 3-28; B, 2-22. (Fig. 8).
Plocamium coccineum (Huds.) Lyngbye. A, 14-26; B, 10-15; D, 2. (Fig. 8).
Plocamium costatum (C. Ag.) H. & H. A, 15-20; B, 6-10. (Fig. 8).
Plocamium dilatatum J. Ag. A, 15-20; B, 10-16. (Fig. 8).
Plocamium leptophyllum Kuetzing. A, 20-24; B, 16-20.
Plocamium mertensii (Grev.) Harvey. A, 10-25; B, 6-16. (Fig. 8).
Plocamium patagiatum J. Ag. A, 10-25. (Fig. 8).
Plocamium preissianum Sonder. A, 3-17; B, 10-20 (Fig. 8).

Phacelocarpaceae

Phacelocarpus apodus J. Ag. C, 2-5. (Fig. 15).

Phacelocarpus labillardieri (Mert.) J. Ag. A, 5-26; B, 6-15. (Figs. 8-12).

Nizymenia australis Sonder. A, 13-25; B, 6-16. (Figs. 8, 11, 12, 16).

Solieriaceae

Callophycus laxus (Sonder) Silva. A, 10-20. (Fig. 8).

Rhabdoniaceae

Areschougia dumosa Harvey. A, 16-24; B, 13-16. (Fig. 8).

Areschougia laurencia (H. & H.) Harvey. B, 6-10.

Rhodophyllidaceae

Rhodophyllis marginalis J. Ag. B, 13-18.

Rhodophyllis membranacea (H. & H.) Harvey. A, 13-26; B, 10-23. (Figs. 8, 9, 11, 16).

Rhodophyllis multipartita Harvey. A, 10-26; B, 6-23. (Figs. 8-12, 16).

Rhodophyllis ramentacea (C. Ag.) J. Ag. A, 13; B, 13-18.

Hypneaceae

Hypnea episcopalis H. & H. A, 16-18; B, 6-16.

Mychodeaceae

Mychodea hamata Harvey. A, 15-18; B, 6-8. (Fig. 16).

Ectoclinium latifrons J. Ag. A, 13-17.

Acrotylaceae

Acrotylus australis J. Ag. B, 6-13.

Peltasta australis J. Ag. A, 10-16; B, 13-16.

RHODYMENIALES—Rhodymeniaceae

Rhodymenia australis Sonder. A, 13-26; B, 13-23. (Figs. 8, 11).

Champiaceae

Champia tasmanica Harvey. A, 16-22.

CERAMIALES—Ceramiaceae—Crouaniceae

Gattya pinnella Harvey. B, 16-21.

Antithamnieceae

Acrothamnion preissii (Sonder) Woll. A, 16; B, 6-13. (Epiphytic on *Gelidium australe*, *Pterocladia lucida*, *Nizymenia australis* and *Ballia callitricha*).

Ballia callitricha (C. Ag.) Kuetz. A, 5-25; B, 5-23. (Figs. 8, 11).

Ballia mariana Harvey. A, 10-26; B, 13-26. (Fig. 8).

Spongoclonieae

Haloplegma preissii Sonder. B, 16-26.

Spongoclonium sp. A, 13-20; B, 13-26.

Other species of *Spongoclonium* occur at Toad Head and Oedipus Point in 16-26 m. The species of this genus are confused and await monographic study.

Griffithsieae

- Neomonospora elongata* (Harvey) Womersley. A, 19-26; B, 13.
Neomonospora griffithsioides (Sonder) Womersley. B, 6-23.

Spyrideae

- Spyridia opposita* Harvey. A, 15-20; B, 10-13.

Ptiloteae

- Euptilota articulata* (J. Ag.) Schmitz. A, 10-20; B, 6-23. (Figs. 8, 16).

Delesseriaceae-Hypoglossum group

- Hypoglossum protendens* J. Ag. A, 16-26; B, 13. (Fig. 8).

Hemineura group

- Hemineura frondosa* (H. & H.) Harvey. A, 16; B, 19-26.

Phycodrys group

- Crassilingua marginifera* (J. Ag.) Pap. A, 10-19; B, 13-16.
Halicnide similans J. Ag. A, 16-26; B, 16-22.

Cryptopleura group

- Acrosorium uncinatum* (J. Ag.) Kylin. B, 19. Common as small plants on other algae in various depths of A and B.
Hymenena multipartita (H. & H.) Kylin. A, 13-26.

Dasyaceae

- Dasya ceramioides* Harvey. B, 16-26.
Heterosiphonia australis (J. Ag.) De Toni. A, 21-26.

Rhodomelaceae—Polysiphoniaceae

- Polysiphonia nigrita* Sonder. B, 3-10. Epiphytic on *Acrocarpia*, *Scytothalia* and *Cystophora subfarcinata*.

Amansieae

- Osmundaria prolifera* Lamx. A, 18; B, 5-22. (Fig. 16).

Laurencieae

- Laurencia clavata* Sonder? A, 13-26; B, 6-23. (Fig. 16).
Laurencia elata (C. Ag.) Harvey. A, 6-10; B, 13; C, 1-2.
Laurencia filiformis (C. Ag.) Munt. B, 6-23.

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EXPLANATION OF PLATE

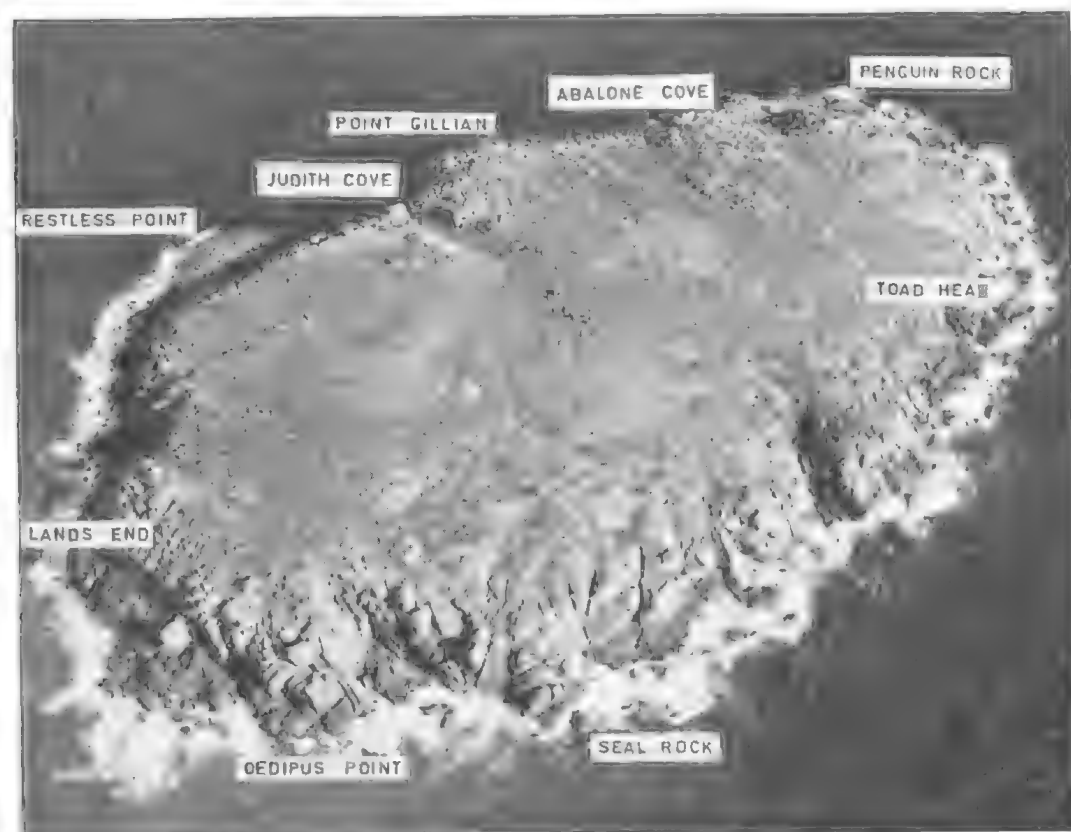
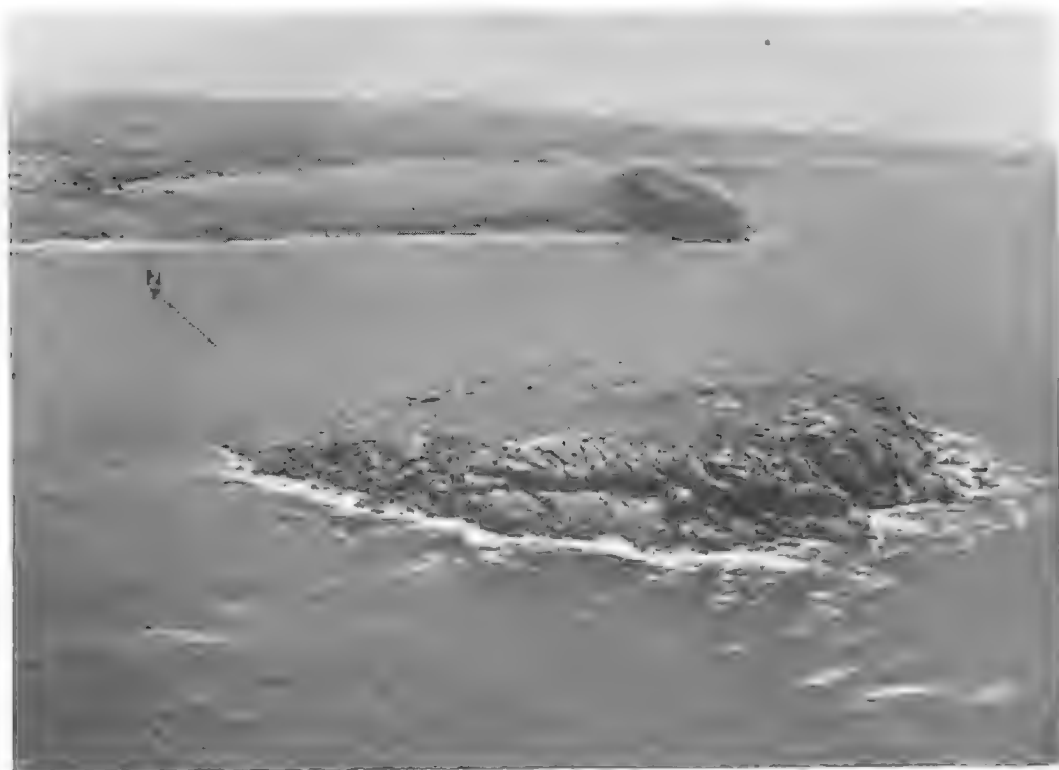
PLATE 1

Fig. 1. Aerial photograph of West Island showing Encounter Bay and Victor Harbor to the north east.

(photograph A. R. Milne)

Fig. 2. Aerial photograph of West Island showing the main localities.

(photograph A. R. Milne)



THE SUBLITTORAL ECOLOGY OF WEST ISLAND, SOUTH AUSTRALIA.

2. THE ASSOCIATION BETWEEN HYDROIDS AND ALGAL SUBSTRATE

BY *S. A. SHEPHERD[†]* AND *JEANETTE E. WATSON*

Summary

The association between hydroids and benthic algae has been examined at West Island in Encounter Bay. Thirty-eight species of hydroids (of which 17 are new records for South Australia) are recorded epiphytic upon algae. Of these, 17 species show preference for particular algal substrates to a striking degree while 5 other species of very common occurrence are less selective of substrate, each being recorded on at least 10 species of algae.

Observations upon the nature of preferred and unfavoured algae suggest that some hydroid larvae are positively rugotactic, favouring rough, flat or depressed algal surfaces and avoid filamentous or mucus-coated species. The biochemical properties of some algae and the presence of a suitable surface film appear equally important so increasing the ecological possibilities of substratum preference by hydroids. Red algae (with 38 species) are a more favoured substrate than brown algae (with only 15 species).

The most important factor determining the distribution of epiphytic hydroids in the sublittoral is the presence of suitable substrate algae. At West Island, optimal conditions exist in the mid-sublittoral between 12 and 20 m on the rough windward shore, where there is a rich red algal flora; here, there is an abundant epiphytic hydroid fauna in terms of species and density.

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INTRODUCTION

Reports upon the association between benthic animals and algae in the sublittoral zone are rare. Rogick and Croasdale (1949) in the region of Woods Hole, U.S.A. and Ryland (1962) on the English Coast have noted the association of bryozoa and algae; Sloane et al. (1961) has reported upon the fauna on algae in Lough Ine, Eire. Following the account of Kato et al. (1951), Nishihira (1965, 1966, 1967a, 1967b, 1968a, 1968b) studied the ecology of hydroids in the region of Asamushi, Japan.

Detailed reports of this kind for Australian waters are lacking although fragmentary information about the algal substrate of hydroids may be found in the papers of Bale (1884), Bartlett (1907), Mulder and Trebilcock (1911), Blackburn (1937, 1938, 1942), Hodgson (1950), Ralph (1956) and Pennycook (1959).

This paper is the second of a series of studies upon algae and their associated fauna about West Island, Encounter Bay. An account of the sublittoral environment and of the algal distribution at West Island is given by Shepherd and Womersley (1970).

Hydroids attached to rocky substrates, or found among holdfast fauna are not included in this study and will be the subject of a later paper by the second author. Notes are made upon the abundance, fertile seasons and ecology of the species found. Microslides of hydroids examined in this study are lodged in the National Museum of Victoria, the South Australian Museum and held in the personal collection of the second author.

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TABLE 1

Hydroid epiphytes on algae

o indicates new record for South Australia

* indicates months when fertile colonies found

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
F. CAMPANULARIIDAE												
<i>Campanularia umbellata</i> Mulder & Trebilcock 1914	o											
<i>Campanularia australis</i> Stechow 1924												
<i>Orthopyxis caliculata</i> (Hincks 1853)		*										
<i>Orthopyxis angulata</i> Bale 1914	o										*	*
<i>Obelia geniculata</i> (Linne, 1758)										*	*	
<i>Siliularia bilobata</i> (Coughtrey 1875)	o	*										
F. SYNTHECIIDAE												
<i>Diphasia subcarinata</i> (Bask 1852)												
<i>Synthecium</i> sp.												
F. LINEOLARIIDAE												
<i>Lineolaria spinulosa</i> Hincks 1861	o											
F. HALECHIDAE												
<i>Scorsethia daidala</i> Watson 1969	o	*										
F. SERTULARIIDAE												
<i>Stereotheca elongata</i> (Lamouroux 1816)		*			*		*			*	*	
<i>Crateritheca ucanthostoma</i> (Bale 1882)		*										
<i>Amphisbetia minima</i> (Thompson 1879)		*		*	*			*	*	*	*	*
<i>Amphisbetia maplestoni</i> (Bale 1854)		*		*	*			*	*	*	*	*
<i>Amphisbetia minuta</i> (Bale 1882)	o											
<i>Amphisbetia pulchella</i> (Thompson 1879)	o											*
<i>Sertularia acuta</i> Stechow 1921	o											
<i>Sertularia geminata</i> Bale 1884	o	*							*			
<i>Sertularia mecallumi</i> Bartlett 1907	o	*										
<i>Sertularia macrocarpa</i> Bale 1884	o	*										
<i>Sertularia obliquanoda</i> Mulder & Trebilcock 1914	o	*										
<i>Symplectoscyphus neylectus</i> (Thompson 1879)	o	*						*	*	*	*	
<i>Symplectoscyphus indicus</i> (Bale 1882)	o	*						*	*	*	*	
<i>Symplectoscyphus macrothecus</i> (Bale 1882)	o	*						*	*	*	*	
<i>Sertularella robusta</i> Coughtrey 1875						*		*	*			
<i>Dynomene quadridentata</i> (Ellis & Solander 1786)												
F. PLUMULARIIDAE												
<i>Antennella</i> sp.												
<i>Plumularia alata</i> Bale 1888	o	*										*
<i>Plumularia flexuosa</i> Bale 1894												
<i>Plumularia spinulosa</i> var. <i>spinulosa</i> Bale 1882	o											
<i>Plumularia filiculis</i> Kirchenpauer 1876	o	*								*		
<i>Holopteria aglaopheniaformis</i> Mulder & Trebilcock 1902	o							*				
<i>Pycnotheca producta</i> Bale 1882								*	*			
<i>Aglaophenia plumosa</i> Bale 1882								*	*	*	*	
<i>Thecocarpius divaricatus</i> var. <i>mecoyi</i> Bale 1882	o							*	*	*	*	
<i>Halicornaria longirostris</i> (Kirchenpauer 1872)												
<i>Halicornaria ascidoides</i> Bale 1884	o											
<i>Halicornopsis elegans</i> (Lamarck 1816)												

METHOD

Algae collected at approximately monthly intervals during the algal survey of West Island in 1967 and 1968 (Shepherd & Womersley, 1970) by the first author were examined for the presence of hydroids, and observations were made upon their fertile season. The algae were identified by the first author, and in cases of difficulty, by Dr. H. B. S. Womersley, and hydroid determinations were made by the second author. In addition, algae collected early in the survey in 1965 and 1966 and mounted on herbarium sheets in the Botany Department of the University of Adelaide, were examined by us. Although this material was dried and pressed, it was not difficult to recognize most hydroids. A few species required reconstitution in water before identification was certain, and only *Antennella* sp. and *Synthecium* sp. could not be identified to species. In this way, the common

species of algae were examined on numerous occasions and uncommon species were checked several times.

Abundance of hydroid growth was estimated subjectively by taking into account frequency of occurrence and luxuriance of spread of a colony upon a substrate. This method was found satisfactory as growth was either profuse and occurred on a majority of plants of an individual species or was only occasionally or rarely recorded. Hence the results, based upon a large number of observations at all times of the year give a good overall picture of the incidence of epiphytic hydroids. Nevertheless, it is possible that further collecting will produce additional records as the abundance of some hydroids was found to vary seasonally and from year to year.

RESULTS AND DISCUSSION

The epiphytic hydroids and the months in which they are fertile are recorded in Table 1. Athecate hydroids were not found growing on algae probably because the unprotected hydranth is unable to withstand turbulent conditions.

Some hydroids, listed in Table 2, were found on very few occasions, so that their constant association with particular algae is not established; it is likely that some of these hydroids occur on other substrates as well.

The hydroids listed in Tables 3 and 4 are all associated with particular algae and the results show that these hydroids are selective of substrate in varying degrees. They are discussed in three groups, according to the degree of selectivity. The authors of hydroid species are given in Table 1 and the authors of the species of algae from West Island are given by Shepherd and Womersley (1970).

(a) Species showing least selectivity

The species in this group are:

Amphisbetia minima, *Campanularia australis*, *Plumularia filicaulis*, *Symplectoscyphus neglectus*, *Stereotheca elongata*.

TABLE 2
Hydroids seldom found on algae

Hydroid	Algal Substrate
<i>Amphisbetia maplestoni</i>	<i>Placodium</i> sp.
<i>Amphisbetia minuta</i>	<i>Carpopeltis phyllophora</i>
<i>Antennella</i> sp.	<i>Pterocaulia lucida</i>
<i>Campanularia ambiplica</i>	<i>Seirococcus axillaris</i>
	<i>Crassilingua marginifera</i>
<i>Diplasia subcarinata</i>	<i>Laurencia filiformis</i>
	<i>Metamustophora flabellata</i>
<i>Dynamena quadridentata</i>	<i>Laurencia filiformis</i>
<i>Halicornuria ascidioides</i>	<i>Placodium preissianum</i>
<i>Halopteris aglaopheniiformis</i>	<i>Rhodophyllis multipartita</i>
<i>Lineolaria spinulosa</i>	<i>Carpopeltis phyllophora</i>
	<i>Rhodymenia australis</i>
<i>Plumularia alata</i>	<i>Zonaria spiralis</i>
<i>Plumularia flexuosa</i>	<i>Peyssonellia guianiana</i>
<i>Pycnotheca producta</i>	<i>Rhodymenia australis</i>
<i>Sertularia geminata</i>	<i>Laurencia elata</i>
	<i>Laurencia filiformis</i>
	<i>Acrocarpia paniculata</i>
<i>Sertularia obliquanoda</i>	<i>Gelidium australe</i>
<i>Symplectoscyphus macrothecus</i>	<i>Cystophora subfarcinata</i>
<i>Synthecium</i> sp.	<i>Laurencia filiformis</i>

TABLE 3

Showing hydroids associated with brown algae. v.c. = very common; c. = common; occ. = occasional

	<i>Amphipedia minima</i>	<i>Campanularia australis</i>	<i>Halimnaria longirostris</i>	<i>Obelia geniculata</i>	<i>Guthrieopsis angulata</i>	<i>Guthrieopsis eulabulata</i>	<i>Plumularia filiculis</i>	<i>Plumularia spinulosa</i> var. <i>spinulosa</i>	<i>Scoresbia daidula</i>	<i>Sertularella reclusa</i>	<i>Silicularia bilabiata</i>	<i>Sertularium elongata</i>	<i>Symplectocarpus axillaris</i>	<i>Symplectocarpus neglectus</i>	Number of hydroid species associated with this alga
<i>Lobospira bicuspidata</i>							occ			occ					2
<i>Zonaria angustata</i>	occ									occ					2
<i>Zonaria crenata</i>									vc						1
<i>Zonaria sinclairii</i>	occ		occ										occ		3
<i>Zonaria spiralis</i>	occ														1
<i>Perithalia emudata</i>		occ												occ	2
<i>Ecklonia radiata</i>				vc											1
<i>Acrocarpia paniculata</i>		occ				occ		occ				c.	occ		5
<i>Cystophora monilifera</i>										occ					1
<i>Cystophora moniliformis</i>		occ													1
<i>Cystophora subfarcinata</i>		vc													1
<i>Scytothalia dorycarpa</i>											c				1
<i>Seirococcus axillaris</i>											c		occ		2
<i>Sargassum bracteolum</i>	vc	occ													2
<i>Sargassum reticulatum</i>	occ	occ			occ			occ							4
Number of species epiphytised by this hydroid	5	6	1	1	1	1	1	2	1	3	2	1	3	1	

These are the most common hydroids of the region and several factors appear to contribute to their abundance. Although they occur on numerous species of algae, they are preferentially associated with a few species some of which are very common in the sublittoral, with the result that there is an abundance of available substrate on which their larvae may settle. The fact that three of them (*A. minima*, *S. elongata* and *S. neglectus*) are fertile for most of the year (Table 1) no doubt also contributes to their prevalence (cf. Nishihira, 1966).

(b) *Species showing most selectivity*

Two species were observed in association with only one alga, and one species was observed in association with the two related species of algae. These are:—

Obelia geniculata with *Ecklonia radiata*

Scoresbia daidula with *Zonaria crenata*

Silicularia bilabiata^a with *Scytothalia dorycarpa* and *Seirococcus axillaris*

In the first two cases, the association appears to be obligatory as these two hydroids have not been recorded in southern Australia on any other substrate. (See Womersley, 1967, p. 226; Watson, 1969, p. 115). However, *Obelia geniculata*

^a There is also a solitary record of this hydroid on *Acrocarpia paniculata*.

TABLE 4
Showing hydroids associated with red algae

	<i>Aglaophenia glutinosa</i>	<i>Amphibedictia minima</i>	<i>Amphibedictia pulchella</i>	<i>Climacopora australis</i>	<i>Craterithera acanthostoma</i>	<i>Halicormaria longirostris</i>	<i>Orthopyxis caliculata</i>	<i>Pannularia flicaulis</i>	<i>Pannularia spinulosa</i> var. <i>spinulosa</i>	<i>Setularia robusta</i>	<i>Setularia acuta</i>	<i>Setularia mecallumii</i>	<i>Setularia macrocarpa</i>	<i>Stereothura elongata</i>	<i>Stereothura cylindrica</i>	<i>Symplectosiphonia neglecta</i>	<i>Thoaecarpus dicentrurus</i> var. <i>microgaster</i>	Number of hydroid species associated with this alga
<i>Gelidium australe</i>				occ	occ				occ	occ				c	occ	occ	occ	8
<i>Gelidium glandulaefolium</i>		occ			occ	occ			occ	occ						occ		7
<i>Pterocladia lucida</i>	occ	c		c				occ						occ	occ	occ		7
<i>Corallina</i> sp.		occ																1
<i>Metamastophora subellata</i>		occ							occ	occ								3
<i>Somlethophycus australis</i>		occ	occ												occ			3
<i>Peyssonelia gunniana</i>										occ								1
<i>Carpopeltia phyllophora</i>		c						occ			occ							3
<i>Polyopes constrictus</i>																occ		1
<i>Thamnoclonium dichotomum</i>															occ			1
<i>Callophyllis ocellinea</i>		occ																1
<i>Melanthalia consinna</i>															occ			1
<i>Melanthalia obtusata</i>											occ			c				2
<i>Phaeolocarpus apodus</i>											occ							1
<i>Phaeolocarpus complanatus</i>															occ			1
<i>Phaeolocarpus labillardieri</i>					occ	occ	occ				c	occ		vc	occ	c	occ	9
<i>Nizymenia australis</i>		c						c	occ		c			vc		c	occ	7
<i>Callantheus latus</i>					c										occ			2
<i>Areschougia dumosa</i>															occ	occ		2
<i>Rhodophyllis multipartita</i>		occ					occ			c					occ	occ		5
<i>Plocamium angustum</i>		occ						occ								occ		3
<i>Plocamium rooseae</i>		occ																1
<i>Plocamium costatum</i>		occ				occ	occ						occ					4
<i>Plocamium mertensii</i>	occ		occ				occ						occ			occ		5
<i>Plocamium putagiatum</i>							c					occ				occ		8
<i>Plocamium preissianum</i>	occ	c					occ	occ	c		occ	occ		occ		c	occ	10
<i>Acrotylus australis</i>		occ													occ	c		3
<i>Rhodomenia australis</i>	occ	c	occ	occ			occ	c	occ			occ				occ		9
<i>Acrothamnion preissii</i>				occ														1
<i>Ballia calitricha</i>				c														1
<i>Euptilota articulata</i>																occ		1
<i>Apoglossum tasmanicum</i>		occ		c			c											3
<i>Crassilobus marginifera</i>									occ								occ	2
<i>Hymenena multipartita</i>		c						occ										2
<i>Laurencia fluxus</i>	occ	occ		occ			occ									occ	occ	6
Number of species epiphytised by this hydroid	5	18	3	8	4	4	4	11	5	8	4	7	3	13	5	16	6	

* In this case, the hydroid is usually epizoid on the sponge *Callyspongia* sp. which encrusts the algal surface.

and *Silicularia bilabiata* are recorded growing on *Macrocystis pyrifera* (L.) Agardh in New Zealand waters (Ralph, 1956), and *Obelia geniculata* is reported upon *Laminaria digitata* (Huds.) Lamour. on the British coast (Robins, 1969) and upon *Symphyccladia latiuscula* (Harv.) Yamada by Nishihira (1968) in Japanese waters. Evidently, preference for a particular alga is a local characteristic of both *Silicularia bilabiata* and *Obelia geniculata* and varies over their geographic ranges according to substratum possibilities.

(c) *Species showing some selectivity*

The remaining hydroids in Tables 3 and 4 are all found on relatively few species of algae, indicating that some are more favourable than others; however, only 5 species (*Crateritheca acanthostoma*, *Lineolaria spinulosa*, *Plumularia spinulosa* var. *spinulosa*, *Sertularella robusta* and *Sertularia acuta*) show a strong preference for a particular alga.

Algae as Substrate

It is clear from Tables 3 and 4 that at West Island the red algae as a group are the most favourable substrate for hydroids. Except for three species, brown algae are generally unfavourable and green algae never seem to bear hydroids.

According to Nishihira (1966, 1967a, 1968a) the physical and chemical nature of the substrate is of fundamental importance to hydroid larvae. Our observations are in agreement. Algae with flat laminar thalli, concavities or rugose surfaces are favoured substrate and nearly all red algae on which four or more hydroid species grow have these physical characteristics. Of the brown algae commonly epiphytised, *Sargassum bracteolosum* has flat and somewhat rugose basal fronds and *Acrocarpia paniculata* has a rough and warty stem. However, the attractiveness of other algae without these physical qualities, e.g. *Melanthalia* spp. and *Gelidium* spp. which are mucus-coated or possess finely divided ramuli may depend upon a positive chemotaxis among hydroid larvae as reported by Nishihira (1968b).

Conversely some physical and chemical characteristics of algae may be adverse to hydroids. Generally, filamentous or finely divided algae (e.g. *Ballia mariana*, *Corynospira* spp., *Pterocladia capillacea* and *Halopteris* spp.) do not carry hydroids. Nishihira (1967a) attributed this to the fact that the filaments of such algae are smaller in diameter than the larvae and stolons of hydroids.

The general absence of epiphytes on brown algae is probably due to the presence of tannic substances secreted by their tissues (Conover with Sieburth 1964, Sieburth and Conover 1965). These tannins possess antibiotic properties inhibiting settlement of larvae on the alga, and are found in many brown algae (Ogino 1962, McLachlan and Craigie 1964).

Some red algae (e.g. *Rhodophyllis membranacea*, *Haloplegma preissii* and *Epiphloea bullosa* (?)) also appear to secrete mucus and this may make them unattractive to hydroid larvae. Corallineous species (e.g. *Corallina* spp., and *Amphiroa anceps*) are also not colonised by hydroids.

The oldest part of the thallus of an alga is generally colonised first. *Ecklonia radiata*, which grows at the transition zone between stipe and frond, is usually colonised first on the distal part of the frond whereas red and brown algae which grow apically tend to be colonised first on the stem. Algae in their first season of growth are usually quite clean and this may be a useful field method for aging some species. The evident preference by hydroid larvae for a substrate which has aged may be due to the acquisition by the blade of the alga of a suitable surface film (Nishihira 1968b) or may be due to a seasonal variation or a decline in antibacterial activity by the alga (Sieburth and Conover 1965).

Distribution of Hydroids

In general, the occurrence of epiphytic hydroids appears to be related to the availability of suitable substrate algae rather than to any direct environmental effect. Hence, the distribution of hydroids about West Island is determined by the distribution patterns of its preferred substrates.

For this reason, epiphytic hydroids are relatively scarce on the protected lee shore of the island where brown algae are dominant, but are abundant in the mid and lower sublittoral zones on the rough windward side of the island where there is a rich and varied red algal flora, as described in detail by Shepherd and Womersley (1970). However, the distribution of three hydroids (*Obelia geniculata*, *Orthopyxis angulata* and *Orthopyxis caliculata*) is exceptional as they occur only in fairly sheltered conditions although their host algae are more widely distributed. These species all liberate free-swimming medusae and it is possible that species which reproduce in this way are not adapted to rough conditions.

The abundance of epiphytic hydroids is greater in a shaded micro-habitat than on horizontal rock surfaces, and an alga growing on the former site is generally more heavily epiphytised than the same species growing in a situation which is better lighted. Also, many of the records in Table 2 are from shaded habitats. The increased abundance of hydroids both in species and in density in shade may be due to a preference for lower light intensities or to factors associated with reduced light such as the increased growth of encrusting epibiota on algae in these conditions, resulting in a more attractive substrate.

ACKNOWLEDGMENTS

We are grateful to Dr. H. B. S. Womersley for many algal determinations and helpful criticism of the manuscript, and to the Director and Dr. B. J. Smith of the National Museum of Victoria for the provision of facilities and equipment.

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**A NEW GENUS OF TREMATODE (DIGENEA; GORGODERIDAE)
FROM THE URETER OF TUNA FISH (THUNNUS THYNNUS MACCOYII)
IN AUSTRALIA***

BY HAROLD W. MANTER†

Summary

A large, digenetic trematode is described from the ureter of the tuna *Thunnus thynnus maccoyii* from southern Australian waters. It represents a new genus and species, *Cetiotrema crassum* (subfam. Gorgoderinae) distinguished by the size and shape of the body, the caeca being distant from the sides of the body, the uterus being inter-caecal, the vitellaria arising as three claviform lobes on each side and the seminal vesicle at least partly anterior to the genital pore.

The genus is close to *Phyllodistomum* Braun; *P. carangi* Manter, 1947, is considered to belong to *Cetiotrema*; *P. lancea* Mamaev, 1968 is very similar to *Cetiotrema crassum* in some features but, largely on account of the form of the vitellaria, is retained in *Phyllodistomum*.

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The trematodes described below were sent to me by L. Madeline Angel, of the University of Adelaide, South Australia. They were collected by the Commonwealth Scientific & Industrial Research Organization (C.S.I.R.O.) from East Bass Strait and Kangaroo Island in 1939. Two specimens were collected from each of two tuna fish. The three complete and one incomplete specimens are remarkable for their large size. To the naked eye they suggested in size and shape such trematodes as *Fasciolopsis buski* but were even more muscular.

Each specimen was sharply bent ventrally near midbody and evidently strongly contracted. It was necessary to unfold (or cut) and then compress the specimens before they could be mounted on a slide and studied. After staining in Delafield's haematoxylin, each specimen was clamped between two slides, using brass clamps with screws to compress the slides tightly together, then passed through the alcohols to 100% before releasing. Compression of living specimens at the time of killing is preferred handling, but no important distortion seems to result from considerable mechanical pressure after preservation. However, only limited flattening can be achieved in this way.

The large size of these worms indicates they must bend or curl within the ureter of their host and their mass is such that some injury to the tuna must result. No information on incidence or intensity of infection is available.

Most parasites of such large size, especially when infecting a host of economic importance, are described in early literature. The location in the ureter, an organ often not examined for parasites, may explain why this genus seems to be undescribed.

FAMILY GORGODERIDAE

Cetiotrema crassum gen. nov., sp. nov.

(Figures 1-3)

Host: *Thunnus thynnus maccoyii* (Castelnau); Thunnidae; southern bluefin tuna.

Localities: East Bass Strait and Kangaroo Island, South Australia.

Collected by: C.S.I.R.O.; 1939.

Number: 4 (one incomplete); 2 from 1 host in each locality.

* Studies from Dept. of Zoology No. 419.

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Holotype: South Australian Museum, No. E863.

Paratype: U.S. National Museum, Helminth. Coll. No. 71424.

Description (Measurements on 3 specimens, all somewhat contracted and compressed after preservation. Measurements are in mm unless otherwise indicated): Body very large, thick, muscular, with almost parallel sides, broadly rounded at each end. Length 20.0 to 25.5; width 7.5 to 8.5. Sides of body thin and slightly thrown into short folds. Dorsal surface smooth; ventral surface, where not eroded, covered with minute papillae. Strong longitudinal muscles in parenchyma except near sides of body.

Oral sucker ventral, subterminal, circular, 1.2 to 1.5 wide. Forebody 2.755 to 3.8 long. Acetabulum circular, with circular aperture and longitudinal cavity; 1.235 to 1.615 wide. Sucker ratio 1:1.

Pharynx lacking, but anterior portion of oesophagus thick-walled. Oesophagus (contracted) about 0.348 to 0.536 long; bifurcation slightly nearer oral sucker than to acetabulum. Caeca extending to within 2.185 to 2.7 of posterior end of body; not far apart; dividing body width into approximate thirds.

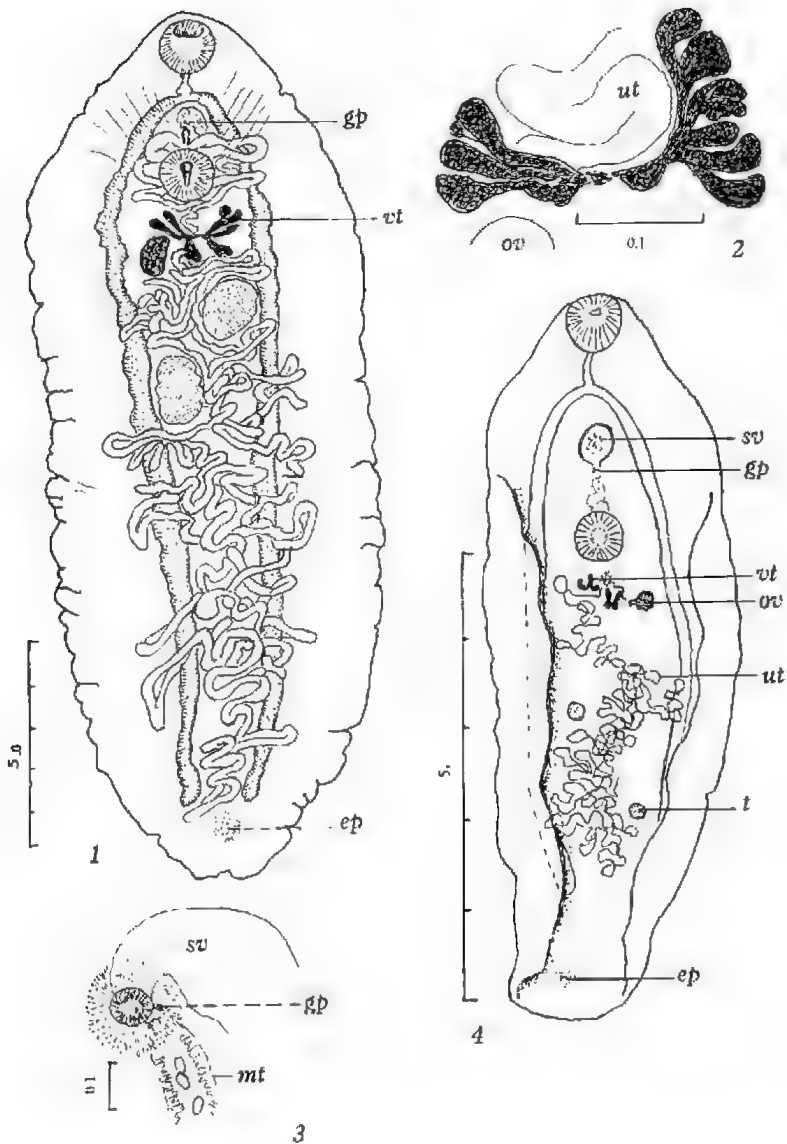
Genital pore median, about midway between acetabulum and bifurcation of oesophagus. Testes a little anterior to midbody, ovoid, smooth or slightly crenulated, diagonal, intercaecal, separated by short space; 1.52 to 2.28 long by 1.14 to 2.09 wide. Seminal vesicle a rounded to elongate sac, inconspicuous, between acetabulum and bifurcation of oesophagus, partly anterior to genital pore; cirrus sac and cirrus absent; prostatic duct short, surrounded by small, radially arranged prostatic cells, antero-dorsal to genital pore.

Ovary ovoid, smooth, to right of midline, pretesticular, separated from anterior testis by uterine coils. Vitellaria immediately anterior and to left of ovary; intercaecal; consisting of claviform lobes, three on each side, sometimes branching. Seminal receptacle lacking. Uterine coils narrow, extending to ends of caeca or slightly beyond; mostly intercaecal but frequently slightly lateral to caeca ventrally; extending between testes, between anterior testis and ovary, and lateral to acetabulum on both sides. Metraterm glandular or at least lined with cells, longitudinal, between genital pore and acetabulum. Eggs 38 to 45 by 20 to 29 microns; operculum apparently lacking; embryo only partially developed.

Excretory pore conspicuous, dorsal, glandular, 1.140 to 1.158 anterior to posterior end of body. Excretory vesicle not seen.

Discussion: Distinctive characters of *Cetiotrema* are large body size; broadly rounded ends; thick body but with thin sides; caeca distant from sides of body which are largely unoccupied by organs; chiefly intercaecal uterus; vitellaria consisting of claviform lobes arising as three on each side; and seminal vesicle at least partly anterior to genital pore. Other Gorgoderinac are generally much smaller.

The genus *Phyllodistomum* Braun, 1899 contains many species occurring in the urinary bladder of both marine and freshwater fishes. These species are thin-bodied and usually have a length of one to a few millimeters. It is, however, the nearest related genus to *Cetiotrema*, and one species, *P. carangis* Manter, 1947 (Fig. 4), 8 mm in length, from *Caranx ruber* (Bloch) in the Gulf of Mexico, can be considered a second species of *Cetiotrema*. It differs from *C. crassum* in smaller size and other characters but agrees in broadly rounded ends; caeca distant from sides of body; vitellaria consisting of three elongate lobes; papillae on the ventral surface; narrow, intercaecal uterine coils, and seminal vesicle anterior to the genital pore. It is from a pelagic fish. Although found in the body cavity, it probably was from the urinary bladder. *Phyllodistomum carangis* was compared with *P. acceptum* Looss, 1901, from the urinary bladder of *Crenilabrus* spp. in the Mediterranean. *Phyllodistomum acceptum* does seem to have somewhat similar



Figs. 1-3. *Cetriotrema crassum*. Fig. 1: Holotype. Ventral view. Fig. 2: Vitellaria of a paratype. Ventral view. Fig. 3: Terminal genital ducts. Ventral view. Fig. 4: *Cetriotrema carangis* (Manter, 1947). Dorsal view. (From Manter, 1947).

All figures were drawn with the aid of a camera lucida. The scale is in mm. Abbreviations: ep, excretory pore; gp, genital pore; mt, metraterm; ov, ovary; sv, seminal vesicle; t, testis; ut, uterus; vt, vitellaria.

vitellaria but the body is more tapered, the caeca nearer the sides of the body, the seminal vesicle posterior to the genital pore, and the uterine coils extend nearly to the sides of the body. Considering these characters together with the host, *P. acceptum* seems to be closely related to *P. (Vitekkarinus) crenilabris* Dolgikh & Naidjenova, 1968 from the Black Sea.

Mamaev (1968) has described a species, *Phyllodistomum lancea*, from the kidney of *Euthynnus affinis* and *Auxis thaazard* in the South China Sea. It is related to *C. crassum* and perhaps should be considered a third species of *Cetiotrema*. It does not appear to have a wide body with rounded ends but its figure shows longitudinal lines suggesting that the sides of the body may be folded inward ventrally. Its seminal vesicle is entirely anterior to the genital pore. However, the vitellaria are rather compact, lobed, grape-like masses rather than elongate tubes, and chiefly on that basis the species is retained for the present in the genus *Phyllodistomum*. It is about the same size as *C. carangis*.

Generic Diagnosis of *Cetiotrema*: Gorgoderidae, Gorgoderinae. Body large, with almost parallel sides and rounded ends; sides of body thin but rest of body may be highly muscular. Minute papillae on ventral surface. Suckers equal or subequal in size. Testes ovoid, diagonal, intercaecal; cirrus and cirrus sac lacking; seminal vesicle at least partly anterior to genital pore. Ovary pretesticular, to right of midline; seminal receptacle lacking. Vitellaria of three claviform lobes on each side, sometimes branching at ends; proovarian. Uterus of narrow coils, mostly or entirely intercaecal. Eggs non-operculate; embryos partly developed. Excretory pore dorsal, well anterior to posterior end of body. Parasitic in the urinary bladder or ureters of pelagic marine fishes. Type species: *Cetiotrema crassum*. Other species: *Cetiotrema carangis* (Manter, 1947) n. comb.

The name *Cetiotrema* is from *cetio* = monstrous or large; and *trema*, for trematode. The name *crassum* is from *crassus* = thick, referring to the thick, muscular body of that species.

Known life cycles of Gorgoderidae are as yet limited to freshwater species, but those of marine species are probably similar. The molluscan host is a bivalve mollusc; cystocercous cercariae develop in daughter sporocysts, emerge, and are ingested by a second intermediate host which, in different species, may be a variety of animals: insect larvae, crustaceans, snails, or tadpoles. In one species, *Phyllodistomum simile* Nybelin, 1926, precocious metacercariae in sporocysts are infective to the final host. Life cycles of marine species probably involve bivalve molluscs and Crustacea.

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THE CAINOZOIC STRATIGRAPHY OF THE EASTERN COASTAL AREA OF YORKE PENINSULA, SOUTH AUSTRALIA

BY WILLIAM J. STUART, JNR.¹

Summary

The Cainozoic succession occurring in coastal cliffs along the east coast of Yorke Peninsula consists of paralic sediments. The Muloowurtie Formation and a partly-included sand tongue, newly described and named Quartoo Sand Member, make up the lower part of the "Muloowurtie Clays". The upper part is re-described and named the Throoka Silts. The Port Julia Greensand, in an expanded sense, is regarded as a member of the Rogue Formation (new name). The overlying Port Vincent Limestone is described and named. The first phase of Cainozoic accumulation commenced with the deposition of Middle to Upper Eocene fluviatile sediments. During early Upper Eocene to Miocene time, sediment accumulation was mainly marine except for a thin interval of sediments, which indicates lagoonal deposition. Marine deposition took place during the Upper Pliocene, and during the Quaternary fluviatile deposition was dominant over marine accumulation in the coastal area.

Earth movements occurred during the Cainozoic Era along ancient fault lines in Cambrian and basement rocks. These movements, which either faulted, folded or tilted Cainozoic beds took place during early Upper Eocene, Oligocene, Middle Miocene to Lower Pliocene and the Quaternary. Facies relationships and the distribution of Tertiary sediments suggest that linear elements played an important role during the accumulation of these sediments, as boundaries between either areas of variable subsidence or areas of relative stability and subsidence. In general, Yorke Peninsula can be subdivided into blocks, which at times during the Tertiary were undergoing reasonably uniform movement, but at other times the blocks moved independently of one another.

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INTRODUCTION

General Statement

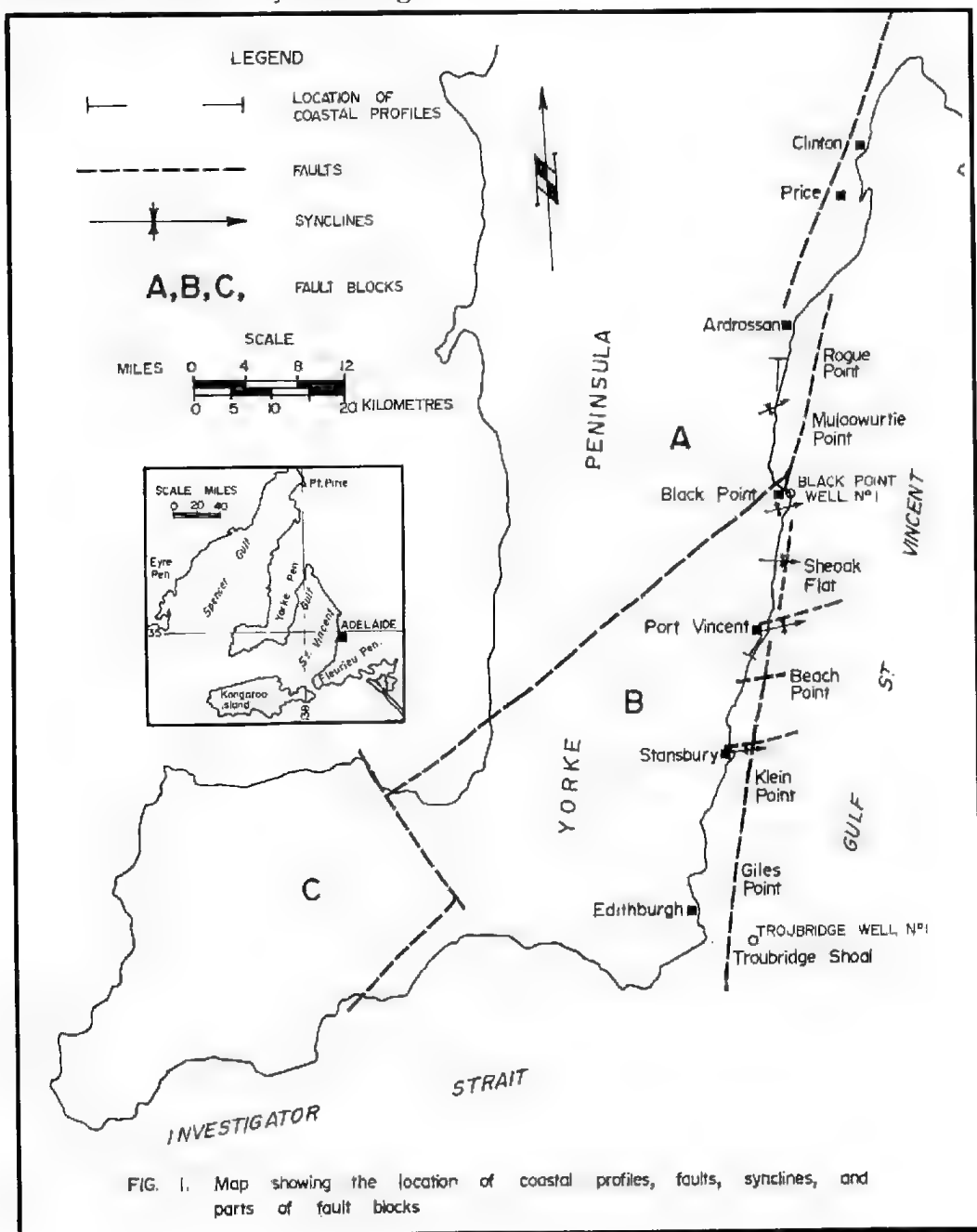
In South Australia, good exposures of Tertiary sediments occur in coastal cliffs along the east coast of Yorke Peninsula. This area is situated on the western margin of the St. Vincent Basin (Fig. 1) where paralic accumulation prevailed during the Cainozoic Era (Claessner and Wade, 1958). Although much work has been undertaken on the stratigraphic relationships of Tertiary strata in the eastern side of the basin, there has been no comprehensive study of these sediments in its western side.

A clear analysis of the geological history of the St. Vincent Basin requires discriminative naming of rock stratigraphic units which form an essential framework of reference, but formal nomenclature for sediments along the east coast of Yorke Peninsula is unavailable in the literature except for the Muloowurtie Clays of Tepper (1879) and the Port Julia Greensand of Crawford (1965). In recent years, the Tertiary sediments have been discussed as time-stratigraphic equivalents of the formally-named Tertiary sediments on the eastern side of the St. Vincent Gulf, but distinct rock units and complex facies variations over short distances warrant introduction of a new stratigraphic nomenclature. Only the Tertiary succession is discussed in detail in this paper, but the general Quaternary succession, as exposed in coastal cliffs, is also included for completeness of coastal sequences. The purpose of this paper is not only to provide a time and rock unit framework, but to decipher the geological history in this area and the role of relative earth movements taking place during the Cainozoic Era.

¹ Geosurveys of Australia Pty. Ltd., Adelaide, S.A.

Procedures

The coastal profiles (Figs. 2, 3, 4) were constructed by sketching coastal cliffs, the heights and distances controlled by topographic base maps and measured stratigraphic columns. The profiles are idealized in the sense that in several places either scree or grasses obscure the sediments. However, where the tracing of beds was difficult, columns were described and measured after the debris was removed by trenching.



Several samples of Tertiary sediment were examined for foraminifera which were used for the purpose of correlation. Locations of these samples are not shown in this paper, but are on file at the Department of Geology, University of Adelaide.

STRATIGRAPHY

General Statement

The Cainozoic succession exposed in coastal cliffs along the east coast of Yorke Peninsula consists of alternating marine and non-marine sediments. Coastal profiles of these sediments are presented in this paper from immediately south of Rogue Point to 8 kilometres south of Port Vincent (Figs. 2, 3, 4). The succession is, in ascending order, comprised of a basal fluvialite sediment unit (un-named), marine Muloozwurtie Formation (redefined), lagoonal Thruoka Silts (new name), marine Rogue Formation (new name), marine Port Vincent Limestone (new name), marine Hallett Cove Sandstone and ?Pleistocene fluvialite and subrecent marine sediments (un-named). In the discussion of these formations it is convenient to subdivide the coastal area into a northern portion between Rogue Point and Black Point and a southern area between Black Point and Edithburgh. The formations of Tertiary age are correlated with sediments of this age which were encountered in the Black Point No. 1 Well, Troubridge No. 1 Well and exposures at other localities on Yorke Peninsula. The discussion begins with the basal Middle to Upper Eocene fluvialite sediments.

BASAL FLUVIALITE SEDIMENTS

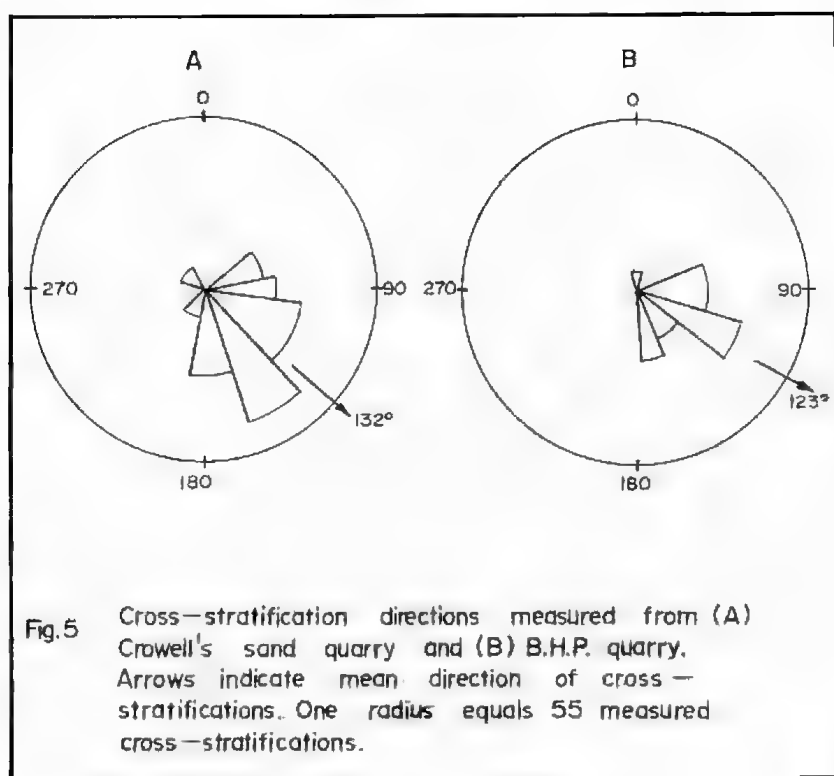
Distribution and lithology

Inland in the vicinity of Ardrossan and Price Townships, Middle-Upper Eocene quartz sands and sandstones with subordinate conglomerates, siltstones and clays are found in isolated outcrops and quarries (Crawford, 1965). These sediments are preserved in hollows within the basement and vary in thickness with a maximum of 11 metres at Correll's sand quarry. A small remnant of fluvialite conglomerate is present immediately south of section 9 (Fig. 2). Sands and conglomerates, 16 metres thick, are found below 155 metres in the Black Point Well. South of Black Point along the east coast of Yorke Peninsula and at lower levels in the Troubridge well, fluvialite sediments of Middle to Upper Eocene age are absent.

Quartz comprises at least 95% of the fluvialite sands, but mica and feldspar are common accessory minerals. Within conglomerates, pebbles are essentially resistant rock-types: quartz, quartzite and vein quartz with subordinate arkosic sandstone. The clay mineralogy of samples from lenticular clays is predominantly kaolinitic with traces of illite and montmorillonite.

The exposed fluvialite sediments are laminated to thinly bedded. They contain small to medium scale cross-stratifications (planar and trough; in the sense of McKee and Weir, 1953). Coarse channel-lag deposits are common over an irregular basement surface which has approximately 5 metres relief in the B.H.P. quarry.

Palaeocurrent analysis of cross-strata was attempted to establish the dominant directions of stream transport of Middle to Upper Eocene sands. It is apparent that only two locations are suitable for direct measurement of current directions in the northern portion of Yorke Peninsula (Fig. 5), so that conclusions can only be tentative. Channel and cross-strata directions in the B.H.P. quarry and Crowell's sand quarry near Ardrossan indicate transport to the east-southeast (Fig. 5). This suggests stream transport towards the present axis of the St. Vincent Gulf. The next phase of sediment accumulation is recorded by the marine Muloozwurtie Formation.



MULOOWURTIE FORMATION

Definition

Tepper (1879) applied the name "Muloowurtie Clays" to a marine sequence between Roguc and Muloowurtie Points of (in ascending order) fossiliferous, ochre-yellow clay with oysters, echinoderms, pelecypods and fish teeth; white plastic clay; one inch of arenaceous limestone with *Fibularia gregata* Tate; 3 to 6 metres of unfossiliferous ochreous clays. The "Muloowurtie Clays" actually consist of biogenic calcarenites, quartz sands, calcareous and glauconitic quartz sands and sandstones and minor thin conglomerates, silts and clays. Because the "Muloowurtie Clays" contain several non-clayey rock-types, the name Muloowurtie Formation is preferable. As used here, it is restricted to sediments below the "unfossiliferous, ochreous clays". The "unfossiliferous ochreous clays" are assigned to the lagoonal Throoka Silts which disconformably overlie the Muloowurtie Formation.

Type Section

The type section of the Muloowurtie Formation is located at Sliding Rocks (Sect. 3, Fig. 2). The formation as restricted is about 12 metres thick and unconformably overlies the Lower Cambrian Kulpara Limestone (or Ardrossan Marble of Tepper). Green glauconitic quartz sands containing thin lenses of pebbles are found in the lower 2 metres of the formation. Subround to subangular pebbles of quartz, quartzite, limestone and arkosic sandstone within the sands were probably derived from local source areas of pre-existing Tertiary sediments and Cambrian rocks. The sands are moderately-sorted and medium- to coarse-grained. Glauconite in the form of pellets and internal moulds of foraminifera rarely exceeds

10% of the bulk composition. The glauconitic sands were not recorded by Tepper, but are here included in the definition of the Muloowurtie Formation.

Richly fossiliferous sands containing a few quartz pebbles gradationally overlies the glauconitic sands. The following fossils were recognized: the echinoids *Fibularia gregata* Tate, *Salenia tertiara* Tate, *Eupatagus*, crinoid plates, brachiopods, lamellibranchs, the bryozoans *Retepora* and *Cellepora*, ostracods and foraminifera. The fossiliferous sands vertically grade to calcareous, silty to fine, quartz sands. The quartz sands decrease as carbonate constituents increase upwards and they grade to silty, biogenic calcarenites. The carbonate constituents consist of numerous foraminifera, small shells and fragments, and common echinoid spines. The clay and silt fraction of the carbonates varies between 10 and 20 per cent. The sediments contain lenticular laminac and very thin beds. Ripple-marks and burrows occasionally occur within the sequence. These sediments are the fossiliferous, ochre-yellow clay and white plastic clay of Tepper. They are about 5 metres thick and often are speckled buff by iron-oxide staining.

The calcarenites in turn vertically grade to yellowish grey, calcareous, very fine to medium quartz sands often argillaceous and silty. They are overlain by resistant, calcareous, very fine to fine quartz sandstones which are very finely-bedded to thin-bedded. The sandstones contain an interbed of pale greenish grey and buff silt. The upper 91 centimetres of the formation consists of variegated, argillaceous, quartz sands interbedded with arenaceous clays. The sediments above the calcarenites probably constitute the arenaceous, yellow clay and sand-rock of Tepper. They are about 4 metres thick.

Distribution and lithology

For about 800 metres north of Sliding Rocks only minor facies variations are found within the Muloowurtie Formation as it gradually dips below sea level (Fig. 2). At Sliding Rocks basal glauconitic sands overlain in part by finely bedded calcareous sands both thin to a depositional edge on the Cambrian Kulpura Limestone.

Immediately south of Sliding Rocks, a second glauconitic quartz sand is found near the middle of the Muloowurtie Formation. It increases in thickness to the south (Sect. 4, Fig. 2) and forms an extension of the Quarton Sand, new name, a Member of the Muloowurtie Formation (p. 160). The sand tongue divides the remainder of the Muloowurtie Formation into lower beds A and upper beds B (informal units) which can be recognized at section 3 and further north (Fig. 2).

The Muloowurtie Formation dips below sea level on the north side of Muloowurtie Point but reappears to the south in coastal cliffs and is traced almost to Section 6 where calcareous sands and arenaceous calcarenites of the lower beds thin to a depositional edge on Precambrian crystalline basement (Fig. 2 just north of Section 6). Because the topography of basement is irregular, they exhibit minor facies changes in the vicinity of a hollow located at sections 6 and 7. At a lower level in the hollow (Sect. 7) glauconitic and richly fossiliferous quartz sands are overlain by calcareous sands and arenaceous calcarenites. They show vertical grain size trends similar to those in the sequence at the type section. At slightly higher levels on the hollow (Sect. 6) a thin sandstone with small to large pebbles of quartz, quartzite and granite gneiss contains occasional brachiopods, and numerous oysters. On nearby basement an oyster was found in growth position. The fossiliferous sandstone is separated from glauconitic and richly fossiliferous sands by calcareous sands and arenaceous calcarenites filling in the hollow. This suggests that the basal glauconitic and richly fossiliferous sands and the fossiliferous sandstone were probably deposited at about the same time on

submarine, low dipping surfaces located at different levels. Oysters flourished in a higher energy environment on the higher surface.

In the vicinity of Harts Mine, the thickness of the lower beds is about 3 metres. A basal poorly fossiliferous transgressive conglomerate with quartz, quartzite and granite gneiss pebbles overlies Precambrian basement (Sect. 8, Fig. 2). On the wave-cut platform, it overlies Cambrian arkoses and contains numerous fossils. At section 8, yellowish grey moderately- to poorly-sorted fine and medium quartz sands with occasional fossils overlie the basal conglomerate. They are overlain by 30 centimetres of resistant, grey-white, very calcareous, coarse to very coarse, quartz sandstone with granules. The basal transgressive conglomerate is stratigraphically controlled by an overall rise of basement beginning about 92 metres south of Harts Mine (Fig. 2). This partly explains the thinning of the overlying quartz sands to less than 1 metre in a southerly direction. The sands also thin by lateral gradation to coarser sands of the Quartoo Sand Member. The boundary between the lower beds and the Quartoo Sands is arbitrarily drawn on Fig. 2.

At Rocky Point about 4 metres of laminated and thin-bedded calcareous sands and biogenic calcarenites overlie a thin basal conglomerate (Sect. 13, Fig. 2). They show vertical grain size trends similar to lower beds A in northern areas. About 1 kilometre south of Rocky Point they dip below sea level. To the north the sediments mostly thin to a depositional edge on Cambrian arkoses and conglomerates. The upper few feet laterally grade to coarse sands and conglomerates, and again the boundary of this part of the Muloowurtie Formation and the Quartoo Sands is arbitrarily drawn on Fig. 2. The depositional thinning of the lower parts of the formation north of Rocky Point and south of Harts Mine accompanied with an increase in quartz constituents and proportionate decrease in carbonate show a depositional high between these two areas.

Considering upper beds B, south from sections 3 to 6: very fine calcareous quartz sandstones and sands laterally grade to lenticular sands, arenaceous calcarenites and arenaceous silty clays (Fig. 2). In general, these sediments become coarser grained to the south. At section 8, thin beds of greenish grey sands are interbedded with these sediments. They are considered thin extensions of the Quartoo Sands.

Although clay minerals are subordinate to quartz and carbonate constituents in the Muloowurtie Formation, montmorillonite and glauconite are common with variable amounts of halloysite and traces of chlorite and illite. Traces of the zeolite clinoptilolite are also present within the formation.

QUARTOO SAND MEMBER OF THE MULOOWURTIE FORMATION

Definition

The name Quartoo Sand Member is applied to variegated pale to dark green, buff, pale grey and red, quartz sands which constitute the upper half of the Muloowurtie Formation in the vicinity of Pine and Rocky Points (Fig. 2). The type section (13) is located at Quartoo Point (now called Rocky Point). Here, 3 metres of quartz sands grade from very fine sands at the base to coarse and very coarse sands with granules near the top of the sequence. They are fairly well-sorted with a deficiency in clay and silt grades. Bands of goethite staining are common near its base and red iron oxides occur at upper levels.

Distribution and lithology

From its type section the Quartoo Sand Member extends northwards to the vicinity of section 9 and gradually becomes coarser grained (Fig. 2). Medium

to very coarse quartz sands with granules and occasional pebbles are predominant. The sands are thin- to thick-bedded in contrast to finer bedding in other parts of the Muloowurtie Formation. The Quartoo Sands first overlie yellowish grey calcareous sands in the lower part of the Muloowurtie Formation with gradational contact, then to the north extend onto basement rocks near section 12. Between sections 9 and 10 the thickness of the member is mostly controlled by erosional irregularities of basement. A maximum thickness of 4 metres is found at section 12. Patches of thin basal conglomerates either are confined to small erosional hollows or lie on low dipping erosional surfaces.

Although erosion has removed the Quartoo Sand Member between section 9 and 10, pale grey and green calcareous fine to coarse quartz sands with granules mostly intertongue and laterally grade to other parts of the Muloowurtie Formation in the vicinity of Harts Mine and further north towards Sliding Rocks (Fig. 2). From immediately south of Harts Mine through Rocky Point the absence of upper beds B could be explained by erosion prior to the deposition of the Throoka Silts, but thin green quartz sands interbedded with the upper beds in the Harts Mine area suggest that the main reason for their absence further south is lateral gradation to the Quartoo Sands. From Harts Mine through section 3 at Sliding Rocks, a poorly fossiliferous greenish grey quartzose sand extension of the Quartoo Sands, 30 centimetres thick, constitutes the uppermost bed of the Muloowurtie Formation (Fig. 2):

An upward increase in grain size is a characteristic textural feature of the Quartoo Sands and its lateral extensions. They are considered regressive, marine sands. Patches of thin conglomerates overlying basement between sections 8 and 10 on the depositional high show the only departure from the coarsening upwards trend. Here quartz sands fine upwards for a few metres above the conglomerates then show the coarsening upwards trend. The conglomerates were probably deposited during the initial ingress of the Upper Eocene sea. Regression is further substantiated between Harts Mine and Sliding Rocks by the stratigraphic distribution of the glauconitic sand tongue separating lower beds A and upper beds B. To the north it becomes moderate- to poorly-sorted with a general decrease in grain size, greener in colour with an increase in glauconite, and more fossiliferous with *Fibularia gregata*, echenoid spines, lamellibranch fragments and foraminifera. The sands of this tongue finally grade northwards to buff speckled yellowish grey, calcareous, fine, quartz sands near the top of the lower beds. This relationship can be seen just south of Sliding Rocks where large sigmoidal ripples are found within a thin gradational unit separating the lower beds and the glauconitic sand tongue. The vertical gradation of biogenic calcarenites to calcareous quartz sands near the top of the lower beds and its counterpart south of the depositional high also suggest regression.

As shown by better sorting within the Quartoo Sands and the rare preservation of fossil fragments and glauconite pellets, they were deposited under higher energy conditions over the pre-existing depositional high then extending south past Rocky Point. The deposition of upper beds B north of the depositional high indicates a return to slightly lower energy conditions before the final regression near the top of the formation.

THROOKA SILTS

Definition and distribution

The name Throoka Silts (from Throoka Creek, Hd. of Muloowurtie) is applied to a thin (2.3 to 3.6 metres) sequence of silts and quartz sands which are the "unfossiliferous ochreous clays" Tepper (1879) recognised between

Rogue and Muloowurtie Points. The type section is located at section 4 between Sliding Rocks and Muloowurtie Point (Fig. 2). The formation is easily recognised by its pale colour streaked with thin bands of goethite iron-staining often parallel with bedding, and Liesegang rings. Except for minor gaps it is traceable in coastal cliffs between Rogue and Black Points. Disconformities separate the lagoonal Throoka Silts from the underlying Upper Eocene Muloowurtie Formation, and the underlying marine, Rogue Formation. These surfaces indicate only small hiatuses.

Lithology

At the type section (4) the Throoka Silts consist of laminated to very thinly bedded quartz sands and subordinate silty and arenaceous clays. No overall vertical or lateral textural trends are apparent. Muscovite is a common accessory mineral and kaolinite is the dominant clay mineral. There are also traces of illite and chlorite.

Over the most southerly kilometre of outcrop, lenticular beds of laminated white and brown arenaceous clays are intercalated within very fine and medium quartz sands and silts. At Rocky Point a 1 metre cross-stratified siliceous medium quartz sandstone containing silicified wood (Howchin, 1918; Glaessner and Wade, 1958; Crawford, 1965) underlies these sediments. Plant impressions are found on weathered bedding planes. The sandstone contains numerous small scale, planar (with subordinate trough) cross-strata. Bedding cannot be traced through the sandstone to adjacent sands and its shape forms a small lentil. This lentil of sandstone only occurs locally and here is included within the Throoka Silts. Howchin (1918) noted "a similar sandstone located 1.2 kilometres north of Muloowurtie Point at a small headland". The second siliceous sandstone is found near the base of the overlying, marine, Rogue Formation. The Throoka Silts are not unfossiliferous as described by Tepper but contain large foraminiferal tests (*Ammodiscus* sp.) which are commonly recognizable in outcrop. Other arenaceous foraminifera and rare Miliolids also are present.

Inland and Subsurface Distribution of the Muloowurtie Formation and Throoka Silts

The Muloowurtie Formation and the overlying Throoka Silts can be seen for only a short distance inland along a few intermittent streams. A road-cut located 250 metres west of Muloowurtie Point contains the upper part of the Muloowurtie Formation, the Throoka Silts and part of the overlying Rogue Formation. The Muloowurtie Formation consists of quartz sands that are similar to those of the Quartoo Sand Member. About 0.8 to 1.6 kilometres inland between Muloowurtie Point and Ardrossan, remnants of the Rogue Formation unconformably overlie basement on hill tops about 61 to 76 metres above sea level. Although erosion has removed parts of the formations and no published subsurface data are available, a section normal to the coastline would probably show facies relationships and depositional thinning similar to those within the Muloowurtie formation between Sliding Rocks and the basement high south of Harts Mine (Fig. 2).

The maximum known thickness of the Muloowurtie Formation is 70 metres in the Black Point well (Fig. 6). Here at 155 metres, the formation overlies fluvial conglomerates mostly consisting of quartz granules. The basal 25 metres of the formation consists of pale grey and yellowish grey, moderately-sorted, medium and coarse, quartz sands with a thin 1.2 metre glauconitic quartz sand located 4 metres from the top of this sequence. The sands are poorly fossiliferous at lower levels with only occasional foraminifera, barnacles and shell fragments,

whereas near the top of this sequence foraminifera, echinoid plates and spines and lamellibranch fragments are common. The basal sands are overlain by pale brown, biogenic calcarenites with some interbeds of brownish grey, calcareous clays and calcareous quartz sands. The calcarenites contain carbonate constituents similar to those in the coastal sequence. Sponge spicules are reasonably common within the clays. Near the top of the formation the calcarenites become arenaceous and are overlain by calcareous, moderately-sorted, medium, quartz sands. In the upper 3 metres of the formation well-sorted medium and coarse quartz sands occur at the same stratigraphic level as the regressive Quattoo Sands at Rocky Point. Between 76 and 79 metres a black lignitic sand and lignite overlies the Muloowurtie Formation. It is about time-equivalent to the Throoka Silts in the coastal sequence and was probably deposited in a marginal swamp.

Although differential movements contemporaneous with deposition account for some of the thickness variation in the Muloowurtie Formation between the coastal sequence and the Black Point well, the abnormal thickness of the formation in the well is here attributed mainly to a differential relief caused by faulting prior to the deposition of the Muloowurtie Formation. This is documented by marine sediments of the Muloowurtie Formation separating the fluvial sediments below 155 metres in the well from an erosional remnant of fluvial conglomerates located immediately south of section 9 (Fig. 2) and from those located about 61 metres above sea level to the north towards Clinton. At least the lower 43 metres of the Muloowurtie Formation in the well is of lowermost Upper Eocene age whereas the surface exposures also of Upper Eocene age are slightly younger (p. 173). The faulting probably indicates a rejuvenation of movement along an ancient northeast-southwest fault zone located in Cambrian and Precambrian rocks.

In the Troubridge well the lower 49 metres of the Tertiary sequence consists of calcarenites, clays and quartz sands. On the basis of foraminifera, it is time equivalent to the Muloowurtie Formation of Upper Eocene age in the Black Point well (Fig. 6). Permian basement in the Troubridge well is overlain by 30 metres of grey-white, fine to medium, biogenic calcarenites with occasional grey, calcareous clays and a basal, yellowish grey, quartz sand. The calcarenites contain bryozoal and shell fragments and foraminifera which are slightly recrystallized. The calcarenite sequence is overlain by 12 metres of pale brown and grey, arenaceous, calcareous clays. The clays contain numerous glauconite pellets and internal moulds of foraminifera at lower levels. Pale brown argillaceous fine biogenic calcarenites, 6 metres thick, overlie the clays. Both the clays and argillaceous calcarenites contain well preserved foraminifera with occasional sponge spicules and *Turritella aldingue*. They constitute the lower part of a clay sequence. The description of rock-stratigraphic units is hindered by the absence of subsurface data from areas of possible occurrence between Troubridge Shoal and Black Point (Fig. 6).

Between 201 and 210 metres in the Troubridge well, dark brown silty clays contain some lignitic fragments, occasional foraminifera and glauconitic pellets. They are dominantly marine but occur at about the same stratigraphic level as the Throoka Silts.

Neither the Muloowurtie Formation nor the Throoka Silts are exposed in coastal cliffs between Black Point and Edithburgh. For about 2.4 kilometres north of Port Vincent and in the subsurface further south, the Rogn Formation unconformably overlies Permian basement. Although erosion by the second transgression that is documented by the lower part of the Rogn Formation could explain the absence of the Muloowurtie Formation and Throoka Silts in this area, the sediments probably thinned to a depositional edge south of Black Point and

seaward of the present coastline (Fig. 6). The absence of derived calcareous material such as lowermost Upper Eocene foraminifera reworked into the Rogue Formation tends to suggest mainly depositional thinning.

ROGUE FORMATION

Definition

The name Rogue Formation (from Rogue Point, Hd. of Muloowurtie) is applied to a mainly marine sequence consisting of quartz sands, sandstones and siliceous sandstones, siliceous and arenaceous limestones, mudstones and clays. Sands and sandstones are more common than other rock-types. Tepper (1879) called sediments between Rogue and Muloowurtie Points at lower levels in the formation the "*Turritella* Grits". Because the formation is characterized by numerous facies changes and erosion which limits its distribution, a composite type section is designated in coastal cliffs from Rogue Point to immediately south of Muloowurtie Point (Fig. 2).

Distribution and lithology

The Upper Eocene to Oligocene Rogue Formation is exposed at low tide at Ardrossan and extends intermittently in coastal cliffs from Rogue Point to 7.2 kilometres south of Port Vincent (Figs. 2, 3, 4). It disconformably overlies the Throoka Silts in the northern area and unconformably overlies Permian basement immediately north of Port Vincent. About 1.6 kilometres west of the coastline and extending northwards from Throoka Creek to 2.4 kilometres northeast of Clinton, remnants of fossiliferous siliceous sandstones interbedded with sands overlie basement on low-lying hills (Tepper, 1879, Howchin, 1918; Crawford, 1965). Tepper (1879) and Howchin (1918) correlated these rocks with siliceous sandstones immediately south of Rogue Point which here are considered part of the Rogue Formation. At Muloowurtie Point, the Rogue Formation is unconformably overlain by the Port Vincent Limestone. In the coastal cliffs south of Black Point, the two formations are conformable.

Between Rogue and Muloowurtie Points, part of the Rogue Formation consists of either thin-bedded, grey and grey-white, calcareous, siliceous quartz sandstones or arenaceous and argillaceous limestones with minor interbeds of brown and green arenaceous and silty clays. These rocks constitute a carbonate-siliceous facies, containing a fauna of numerous *Turritella aldingae*, sponge spicules and other fossils. Silica is disseminated in the sandstones and often forms layers and nodules. It has replaced carbonate in some megafossils. Within a few metres or less the rocks within the carbonate-siliceous facies laterally grade to grey-white and variegated slightly calcareous, quartz sands. The sands are thin- to thick-bedded. They vary in grain size from very fine- to medium-grained with occasional coarse beds. There is a decrease in grain size where the sands laterally grade to rocks in the carbonate-siliceous facies. Thin beds rich in *Turritella* can be traced from the carbonate-siliceous facies into the sands. In some places the sands have been leached of carbonate, but thin beds containing moulds of *Turritella* are still traceable. The carbonate-siliceous facies frequently forms headlands whereas the sand facies forms bays. Each occurs at various stratigraphic levels in the formation.

Immediately north and south of Muloowurtie Point the Rogue Formation forms part of a syncline plunging north of east (Fig. 2). A fault on the north side of Muloowurtie Point accentuates the dip of the Rogue Formation, Throoka Silts and the Muloowurtie Formation. The fault plane is essentially vertical trending 10 degrees on the wave-cut platform. The displacement of the beds, which

are slightly downthrown to the east is considered small, a few metres or less. To the south the fault strikes inland and is covered by soil and calcrete. On the flanks of the syncline the composite thickness of the Rogue Formation is about 30 metres.

About 11 metres of the basal thin-bedded and massive, variegated, moderately-sorted, medium and coarse, quartz sands are exposed immediately north of Muloowurtie Point. The sands become calcareous and contain occasional arenaceous, glauconitic limestones towards Muloowurtie Point proper. They are overlain by 91 centimetres of dark green, glauconitic, quartz sand with occasional casts of lamellibranchs, bryozoans and corals. It is found near the top of coastal cliffs adjacent to the southeast corner of a small bay north of Muloowurtie Point and on the wave-cut platform at Muloowurtie Point. On the southern flank of the syncline pale quartz sands are found at the same stratigraphic level suggesting a facies change at depth near the axis of the syncline. The glauconitic sand is overlain by about 15 metres of pale grey and grey-white calcareous, very fine to fine, quartz sandstones with some thin, hard limestones (Sect. 5, Fig. 2). The sandstones are thin- to thick-bedded. In some beds, burrows are filled with glauconite while others contain siliceous nodules and sand-pipes. Only a few megafossils are found in these rocks.

Near the axis of the syncline at Muloowurtie Point, soft yellowish grey, well-sorted, very fine to fine, quartz sands constitute the upper 4.5 metres of the Rogue Formation. They contain even and wavy, very thin bedding, faintly visible, small scale, cross-stratifications and occasional symmetrical ripple-marks. Although the areal extent of the outcrop is small, the sediments, sedimentary structures and rare fossils suggest a beach environment and/or possibly backshore drifting sands.

Between sections 5b and 6, stratigraphic relationships between the sand facies and carbonate-siliceous facies are similar to those north of Muloowurtie Point in the Rogue Formation except that some sandstones have been cemented by secondary iron-oxides (Fig. 2).

Between Harts Mine and Black Point, the lower part of the Rogue Formation consists of variegated grey, red and buff, medium to coarse, quartz sands (Fig. 2). The carbonate-siliceous facies is absent in this area. The sands are very thin- to thinly bedded or often massive. They contain thin lenses of small quartz and quartzite pebbles. At lower levels the bedding is either even or lenticular with occasional ripples. At upper levels weathering has reorganized the sands and bedding features are obliterated. The bedding is not typical of a fluvial environment but could indicate a marine or beach environment. Occasional moulds of *Turritella* are found at lower levels in the formation immediately south of Rocky Point. They indicate marine influence although their lateral distribution is not great. A near shore, littoral to sublittoral environment is suggested for these sands. Their distribution is similar to the Quartoo Sand Member of the Muloowurtie Formation. They also indicate a higher energy environment than their fossiliferous counterparts to the north, suggesting rejuvenation of the depositional high from Harts Mine in the north to past Rocky Point in the south.

Between Port Julia jetty and Port Vincent (Fig. 3), a composite thickness of the Rogue Formation ranges between 26 and 32 metres. The basal beds of the formation are only exposed for a distance of 2.4 kilometres north of Port Vincent. Here the lower 11 metres of the Formation consist of alternating calcareous quartz sandstones and laminated silty clays. The clays contain numerous *Chlamys* whereas the echinoid *Duncanaster* is present in the sandstones. North of section 23 these beds dip below sea level.

The middle part of the Rogue Formation mostly consists of yellowish grey and grey-white, moderately-sorted, fine to medium, quartz sands and sandstones. They are intermittently exposed in coastal cliffs between Port Vincent and Sheoak Flat, further north at the base of section 15 and south of Port Vincent between section 25 and a small creek south of section 26 (Figs. 3; 4). Over this distance the sands and sandstones are about 6 to 8 metres thick. Immediately north of section 21 (Fig. 3) the uppermost sands laterally grade to calcareous siliceous sandstones which are similar to those in the carbonate-siliceous facies located in the northern area. Between Port Vincent and section 21 (Fig. 3), a resistant calcareous medium to coarse sandstone abruptly overlies the lower part of the Rogue Formation. Numerous low angle planar cross-stratifications within the sands are mostly oriented in a northerly direction (Fig. 3). The sands are mostly massive but contain very thin to thin bedding and occasional ripples. The middle part of the formation is poorly fossiliferous except near the top and base of the sequence where foraminifera become more common.

Between Port Julia and Port Vincent, the upper part of the Rogue Formation consists mostly of interbedded, poorly-sorted, fine and medium quartz sands and sandstones with variable amounts of carbonate and clay. Richly glauconitic sandstones and mudstones, calcareous claystones, arenaceous limestones and siliceous sandstones are less common. Numerous facies changes take place over short distances and specific rock-types are shown in sections 14 to 21 (Figs. 3; 4). The upper part of the formation is more fossiliferous than the middle portion. Foraminifera, ostracods, lamellibranchs, gastropods, bryozoans, sponge spicules and sharks' teeth are present. A resistant yellowish grey calcareous and siliceous sandstone 13 metres above the base of section 15 (Fig. 3) contains the gastropod *Turritella tristira* whereas beds below this sandstone contain *Turritella aldingae*. Variegated poorly-sorted medium quartz sandstones with *Chlamys* and other fossils oriented along the bedding gradationally overlie the middle part of the Rogue Formation. Most of the remaining rock-types in the upper part of the Rogue Formation display very thin to thick bedding. Irregularly lenticular bedding and burrows also are present.

At section 15 (Fig. 3), pale green slightly glauconitic quartz sands constituting the uppermost beds of the Rogue Formation laterally grade to calcareous arenaceous claystones in the north and south flanks of a fold. The claystones are gradationally overlain by arenaceous, bryozoal calcarenites (Port Vincent Limestone). These can be traced southwards near beach level almost to section 19. Here the Rogue Formation and Port Vincent Limestone have been uplifted along a high angle reverse fault. The claystones in the Rogue Formation again laterally grade to mostly pale green, quartz sands which are located on the upthrown side of this fault. Leaching may be invoked to account for the northerly sands at section 15 but is probably not the explanation of sands underlying bryozoal calcarenites at section 19. The change to sands on the crests of these small folds seems more likely to indicate mild structural growth contemporaneous with deposition.

From section 21 through section 22 the upper part of the Rogue Formation has been leached of carbonate. Sandstones, sands and clays form a sequence of beds which contain variable amounts of secondary iron-oxides and silica (Sect. 22, Fig. 3). Facies changes between sandstones, argillaceous sandstones and arenaceous clays can be recognized. These rocks are traceable to calcareous counterparts.

The uppermost beds of the Rogue Formation south of Port Vincent consist of grey and buff, medium, quartz sandstones with interbeds of thin brown, green and buff arenaceous mudstones (Sect. 24, Fig. 4). They laterally grade to poorly-

sorted, medium, quartz sands with granules near Devils Gully. Further south at section 26, the sands are about 6 metres thick. These sands contain patches of green colouring and are less sorted than the underlying grey quartz sands near the middle of the Rogue Formation. They can be traced through a badly weathered area between section 27 and the first small creek immediately to the north (Fig. 4). Near section 27 the sands laterally grade to calcareous and argillaceous, quartz sandstones and arenaceous limestones which gradually dip below sea level to the south.

Clay minerals in the Rogue Formation are mainly montmorillonite, mixed layered montmorillonite and glauconite with variable amounts of illite. The zeolite clinoptilolite is fairly common in marine sands at the type section and very common in the upper part of the formation south of Black Point.

Many slump-blocks consisting of parts of the Rogue Formation and overlying sands, clays and calcrete are found between Port Vincent and section 23 (Fig. 3). The clays in the lower part of the Rogue Formation, often saturated with water, provided a slippage plane for these blocks.

Subsurface and Correlation

In the Black Point well the lower 14 metres of the Rogue Formation consist of alternating brown, moderately- to well-sorted, coarse quartz sands with occasional pebbles, dark grey and grey, silty to very fine quartz sands and arenaceous, silty clays (Fig. 6). Occasional glauconite pellets, pyrite, muscovite and lignitic fragments are found in these sediments. They contain a fauna of small foraminifera, ostracods, lamellibranch shells and fragments, sponge spicules and the gastropod *Turritella aldingae*. It is likely that a facies change takes place in the subsurface towards the northeast because quartz sands predominate in the lower part of the formation at Rocky Point. In the Black Point well the alternating sands and clays are found at a stratigraphic level similar to that of sands and clays constituting the lower part of the Rogue Formation near Port Vincent. Further south at the Adelaide Cement Quarry, about 9 to 15 metres of quartz sands overlie Permian basement in the subsurface. Thus, the alternating sands and clays to the north probably grade to quartz sands in the subsurface towards the south (Fig. 6). In the Troubridge well, marine pale and grey calcareous arenaceous clays between 192 and 204 metres constitute the upper part of the clay facies and are correlated with the lower part of the Rogue Formation in other areas.

Mostly grey and dark grey fairly well-sorted medium and coarse quartz sands are found between 55 and 69 metres in the Black Point well. The sands contain lignitic fragments and occasional marine foraminifera. At higher levels glauconite pellets and occasional *Turritella* are present. The sands occur at a stratigraphic level similar to those constituting the middle part of the Rogue Formation in coastal cliffs south of Black Point (Figs. 3; 6). Further south, grey argillaceous quartz sands and silts between 186 and 192 metres in the Troubridge well are about time-equivalent to the sands constituting the middle part of the formation in the coastal cliffs (Fig. 6). In the coastal cliffs and the Black Point well these poorly fossiliferous and fairly well-sorted sands indicate a higher energy environment than laminated to finely bedded clays in the lower part of the formation. At upper levels these sands indicate a slightly lower energy environment in the coastal sequence because they here become more fossiliferous and then are gradationally overlain by poorly-sorted, fossiliferous sandstones of Upper Eocene age in the upper part of the formation. The deposition of these sands lasted slightly longer in the Black Point well and they also correlate with Upper Eocene beds

In the upper part of the formation in coastal cliffs to the south. In the well marine foraminifera of Upper Eocene age are rare below 55 metres in the coarse sands whereas foraminifera of Oligocene age are fairly common at 53 metres in finer sands. The stratigraphic relationship of the sands in the well to those in the southerly coastal cliffs suggests regression and probably still stand followed by a northerly component of transgression. Further south, the Upper Eocene beds in the upper part of the Rogue Formation in the coastal sequence correlate with the lower 6 metres of the Port Vincent Limestone in the subsurface at the Adelaide Cement Quarry and the underlying 9 to 15 metres of sand (Fig. 6).

In the Black Point well the sediments between 55 and 82 metres mostly correlate with the Rogue Formation at its type area. Quartz sands above 55 metres in the well gradually fine upwards until pale yellowish grey calcareous very fine to fine quartz sands constitute the upper 18 metres of the formation. These sands correlate with the uppermost part of the Rogue Formation of Oligocene age and part of the Port Vincent Limestone of Oligocene and lowermost Lower Miocene ages in the coastal cliffs south of Black Point and in the Troubridge well (Fig. 6). Although erosion has removed most of the Rogue Formation a short distance inland and subsurface data is unavailable from areas of possible occurrence, it is probable that most of the formation consists of sands and sandstones similar to those both to the north and south.

The maximum known thickness of the Rogue Formation, 52 metres, is found in the Black Point well. The formation becomes thinner to the south by lateral gradation to part of the Port Vincent Limestone and by depositional thinning of the lower part of the formation which documents the second ingression of the Upper Eocene sea. At Muloowurtic Point the unconformity at the top of the Rogue Formation suggests that thinning in the north was probably controlled by erosion or non-deposition prior to the deposition of the Port Vincent Limestone.

PORT JULIA GREENSAND MEMBER OF THE ROGUE FORMATION

Definition and distribution

The name Port Julia Greensand was used by Ludbrook (1963) and later was formally designated a formation by Crawford (1965). The name was applied to a thin (46 cm) bed of glauconitic sandstone which outcrops for about 200 metres near the base of coastal cliffs 250 metres south of Port Julia jetty (Sect. 15, Fig. 3). The Port Julia Greensand (Member) as used in an expanded sense here (Fig. 3) is of Upper Eocene age and stratigraphically located near the base of a variable sequence of sandstones with occasional carbonates, glauconitic sandstones and mudstones, and calcareous claystones. All these rocks are here considered the upper part of the Rogue Formation. The separation of the Rogue Formation consisting of mostly sands and sandstones from the two distinct rock-stratigraphic units, the underlying Throoka Silts in the northern area and the overlying Port Vincent Limestone, is practical on the east coast of Yorke Peninsula.

Immediately south of section 15 the Port Julia Greensand (in the sense of Crawford, 1965) laterally grades to less glauconitic quartz sands. A second glauconitic sandstone or mudstone is now present 61 centimetres higher in the succession. Glauconitic sandstones and mudstones are found at about this stratigraphic level between Port Julia jetty and Port Vincent (Fig. 3). About 5 metres above these rocks in the vicinity of section 15, variegated red, green and buff sandstones and mudstones also are partly glauconitic and can be traced intermittently in coastal cliffs. Both to the north in the Black Point well and to the south of Port Vincent in coastal cliffs the Port Julia Greensand has laterally graded

to quartz sands which are found at a similar stratigraphic level. The Port Julia Greensand here is considered a mappable member of the Rogue Formation when expanded to include the variegated sands that include the lower glauconitic sandstones and mudstones at the type area.

Lithology

The Port Julia Greensand varies in composition between a green glauconitic quartz sandstone and an arenaceous glauconitic mudstone. It contains a fauna of numerous lamellibranchs, gastropods, corals, bryozoans and other fossils. Occasional carbonate shells have been replaced by glauconite whereas internal and external moulds of fossils are predominant. Faecal pellets, pellets and internal moulds of foraminifera are common. Occasional opaque minerals are present but constitute less than 0.5% of the bulk composition.

PORT VINCENT LIMESTONE

Definition and Distribution

The name Port Vincent Limestone is applied to a distinctive rock stratigraphic unit consisting of bryozoal limestones which are exposed intermittently in coastal cliffs between Port Julia and Edithburgh (Figs. 1, 3; 4). In this area it gradationally overlies the Rogue Formation. An angular unconformity separates it from the Upper Pliocene marine sediments. An erosional remnant of bryozoal limestone at Muloowurtie Point is presumably of this formation; it unconformably overlies the Rogue Formation. The type section is located immediately south of Port Vincent at section 14 (Fig. 4).

The maximum thickness of the Port Vincent Limestone is 125 metres in the Troubridge well (Fig. 6), and was deposited during the uppermost Upper Eocene to Middle Miocene. The formation thins northwestward to about 40 metres in some bores at the Adelaide Cement Quarry. It also thins to the north, where only 3 metres of bryozoal limestone are exposed 250 metres south of Port Julia and 6 metres thickness in the Black Point well. In the coastal area, the formation is mostly of Oligocene and Lower Miocene age whereas in the Black Point well and at Muloowurtie Point it is only of Lower Miocene age. Thinning is explained by the angular unconformity at the top of the formation, lateral gradation to the Rogue Formation, and minor diastems within the formation.

Lithology

The lower 9 metres or less of the time-transgressive Port Vincent Limestone is often arenaceous. It contains very fine to fine grains of quartz in the Troubridge well; coarser grains of quartz are found in the coastal area and near the base of bore No. 35 at the Adelaide Cement Quarry.

Pale grey and grey-white bryozoal calcarenites varying in grain size from fine to very coarse are found in the Troubridge well. The finer grained calcarenites contain variable amounts of micrite with secondary growths of the sparry cement. Hard, coarse-grained calcarenites located at 152 metres and in the upper 46 metres of the formation are moderately-sorted and contain sparry cement composed of crystals 15-50 μ in diameter. The limestones contain rare glauconitic pellets.

From the type section (14) to the vicinity of Giles Point, pale grey and dark yellowish grey medium to very coarse bryozoal calcarenites and calcirudites are traceable. Although the limestones are mostly massive, they contain some lenticular, thin beds containing numerous *Chlamys* and other fossils oriented along

bedding planes. At lower levels grey-white to pale pinkish white, well-sorted, bryozoal calcirudites contain bryozoal fragments ranging in size from 2 to 15 mm.

Pale grey and grey-white bryozoal limestones laterally grade to hard pink, pinkish grey and orange-red calcarenites and calcirudites near the base of coastal cliffs in the vicinity of Beach Point and Klein Point (Fig. 1). The hard limestones are usually associated with small faults, folds and fractures. The voids within the limestones are filled with sparry cement. In a few cases the sparite is confined to well-sorted limestone beds that can be traced laterally. It often accentuates small to medium scale, trough and tabular cross-strata. At the northernmost outcrop at Beach Point an erosional surface, considered a local diastem, separates hard pink calcarenites from soft yellowish grey and grey-white calcarenites. The latter contain a few reworked pebbles of pink limestone which indicate an early introduction of cement. On the other hand, the soft limestones gradually become harder and contain sparry cement indicating at least two periods of cementation. Secondary cementation of limestone along fractures is also common.

About 6 metres above the base of pale yellowish grey and dark yellowish grey bryozoal calcarenites between section 21 and Sheoak Flat (Fig. 3), thin-bedded limestones contain lamellibranchs and other fossils which are broken and show signs of abrasion. In contrast to these beds there are occasional intercalated lenticular thin beds containing delicate lamellibranchs and bryozoans which show little sign of abrasion. They are also found north of Sheoak Flat at section 20 where they form lenses at the base of the formation. On the down-thrown side of a reverse fault north of section 20, blocks of bryozoal calcarenites have been rotated during faulting.

Although bryozoans are the dominant biogenic constituents, foraminifera, echinoids, lamellibranchs, brachiopods and scaphopods are present. The echinoid *Loxenia woodsi* and the lamellibranch *Eotrigonia semiundulata* are found in the bryozoal limestones of uppermost Oligocene and Lower Miocene Age. *Loxenia woodsi* is very common in Lower Miocene yellowish grey bryozoal limestones at Muloowurtie Point; at upper levels in bryozoal limestones immediately south of Sheoak Flat; in dark yellowish grey resistant limestones forming the upper parts of coastal cliffs intermittently between section 27 and Giles Point; in coastal cliffs at Edithburgh.

Near Muloowurtie Point a thin transgressive sand, maximum thickness 1-2 metres, occurs at the base of an arenaceous, moderately-sorted, bryozoal calcarenite (Sect. 5b, Fig. 2). They show a discordance of about 2" with the underlying Rogue Formation. The erosional surface is synclinal in form with a maximum dip of 5° on the northern flank and less on the southern flank. The basal sands are coloured buff and pale green, and grade from moderately-sorted fine sands at base to moderately- to poorly-sorted very coarse sands with granules at upper levels. Quartz is the predominant constituent with grains of granite gneiss and arkosic sandstone. These constituents are also found within the overlying coarse calcarenites which contain intercalated thin beds of very fine to fine biogenic calcarenites.

OTHER EXPOSURES ON YORKE PENINSULA

Glaessner and Wade (1958), Ludbrook (1963) and Crawford (1965) have shown or summarized the distribution of bryozoal limestones on Yorke Peninsula. At most localities remnants of bryozoal limestones unconformably overlie pre-Tertiary sediments and basement. Remnants located at Urania and in the sub-surface at Minlaton and upper Yorke Valley (Crawford, 1965, Maitland Sheet)

suggest that the Port Vincent Limestone overlapped at least the upper part of the Rogue Formation onto basement. Slight regression and stillstand near the middle of the formation may indicate mild uplift and possibly slight erosion of the lower part of the formation prior to the major transgression. Remnants located on the west and southern coasts indicate that basement highs were present during deposition of Upper Eocene and possibly lowermost Oligocene Rogue Formation. On the northern portion of Yorke Peninsula, remnants of a later marine deposit, uppermost Lower Miocene and Middle Miocene bryozoal limestones with *Lepidocyclus* in their lower portion overlie basement in the Melton area. Lindsay (1970) has indicated that these Miocene sediments record at least 2 marine transgressions in areas north of Melton.

The bryozoal limestones in the southern portion of Yorke Peninsula are hard, pink, red and white calcarenites and calcirudites cemented by sparite. They are often arenaceous at lower levels. Crawford (1965) formally applied the name Port Turton Limestone which was informally used by Ludbrook (1963) for a remnant of bryozoal calcarenite about 15 metres thick on the western coast at Port Turton. On the northern part of Yorke Peninsula, the name Melton Limestone, informally used by Ludbrook (1963), was formally applied by Crawford (1965) to "30 feet of conglomeratic, sandy, bryozoal cross-bedded limestones rich in *Lepidocyclus*". The limestones at Melton are correlated with hard bryozoal limestones deficient in quartz between 82 and 91 metres in the Troubridge bore. The arenaceous fraction of these limestones and those at Port Hughes contain lithic and crystalline fragments derived from local source areas.

Hard, pale brown, *Lithothamnion* limestones are located 3.2 kilometres south of Cunecliffe at elevations not greater than 136 metres above sea level. They occur at about the same level as the Melton Limestone. *Lithothamnion*, which are characteristic of shallow water, indicate that the sea probably did not cover portions of Yorke Peninsula at greater elevations.

HALLETT COVE SANDSTONE

Distribution and Lithology

Crawford (1965) has used the name Hallett Cove Sandstone for fossiliferous sandstones and arenaceous limestones of Upper Pliocene age on Yorke Peninsula. In the Troubridge well arenaceous limestones of this age are about 30 metres thick whereas on the eastern coast of Yorke Peninsula these rocks rarely exceed 3 metres. In the coastal area these rocks can be intermittently traced from Edithburgh to immediately past the vicinity of the Port Vincent golf course. Over this distance the Hallett Cove Sandstone unconformably overlies the Port Vincent Limestone in the south and the Rogue Formation in the north.

Near Giles Point, arenaceous limestones contain numerous oysters and other fossils (Ludbrook, 1959). These oysters are often oriented parallel to bedding and show contact relationships to one another with medium to coarse-grained quartz sand filling voids. Further north oysters are less numerous but *Marginalia vertebralis* is common with the mollusc *Anodontia sphericula*, other mollusca, and bryozoans.

Between Port Vincent and Sheoak Flat the Hallett Cove Sandstone has been considerably leached of carbonate. Immediately north of the golf course it is mainly medium to coarse quartz sandstone which contains occasional moulds of fossils. Immediately north of section 20 (Fig. 3) the sandstone becomes very argillaceous and ferruginous with a reticulate red and grey mottling. This

mottling results from a later lateritic profile. In coastal cliffs north of Sheoak Flat and on the northern side of the basin marine sediments of Pliocene age are not known. Fluvatile rocks in this area may be partly of Pliocene age but there is no fossil evidence to confirm this.

Quaternary Sediments

As the stratigraphic coastal profiles also show various Quaternary sediments and soil profiles exposed along the east coast of Yorke Peninsula, a general discussion of these sediments is included here.

Fluvial-fan deposits unconformably overlie Tertiary formations immediately south of Rogue Point and in the vicinity of Ardrossan. Tepper (1879) applied the name "Ardrossan Clay and Sandrock" to these sediments which are probably more than 30 metres thick. The fluvial-fan deposits which have been described by Howchin (1918) and Crawford (1965) are mainly arenaceous clays and quartz sandstones with lenses of conglomerate. The conglomerates contain pebbles of quartz, quartzite, feldspar, arkosic sandstone and fossiliferous siliceous sandstone. Tertiary formations and basement rocks constituting hills immediately west of the coast were the source for most of these pebbles (Crawford, 1965).

Between Black Point and Giles Point fluvatile quartz sands and arenaceous clays overlie with angular unconformity the Hallett Cove Sandstone, Port Vincent Limestone and Rogue Formation. The angular discordance between fluvatile sands and two of these formations can be seen between Giles Point and Wool Bay (Stuart, 1969; chart 3D). This unconformity indicates that earth movements were still taking place here during the Quaternary. Near Giles Point dark yellowish-grey quartz sands partly fill solution cavities in the Hallett Cove Sandstone and Port Vincent Limestone.

Between Sheoak Flat and Port Julia jetty a reticular red and grey mottling horizon in fluvatile sediments also represent part of a laterite profile (Fig. 3). This profile is not confined to these sands because underlying Tertiary formations have been leached in several places and the mottled horizon also occurs immediately south of Sheoak Flat in sediments which are considered lateral equivalents to the Hallett Cove Sandstone. On both the western and eastern sides of the basin thin lenses and layers of the mineral alunite are commonly associated with these profiles. Below the mottling horizon immediately south of Sheoak Flat, enterolithic folds are found in green arenaceous clays which contain lenses of alunite between bedding planes (Fig. 5). Above the mottling horizon dark yellowish-grey or buff quartz sands contain authigenic ferruginous pisolites. Fluvial fan deposits near Ardrossan also contain this mottling horizon. In this area, the lateritic profile has been truncated and reworked pisolites above this surface were probably derived from areas immediately west of the present coastline.

Arenaceous red and green clays unconformably overlie the earlier fluvatile sediments and Tertiary Formations (Figs. 3; 4). These clays fill solution cavities in the Hallett Cove Sandstone and Port Vincent Limestone to depths greater than 27 metres (Stuart, 1969; Charts 3C,D). At a few localities, pink sands overlie these clays and calcrete soil profiles are well-developed.

Fossiliferous limestones overlie either the Rogue Formation or Port Vincent Limestones on wave-cut platforms at the sites of Tertiary synclines adjacent to Stansbury and Port Vincent. These limestones are tentatively correlated with fossiliferous sediments containing *Anadara trapezia* on the eastern side of the basin where they have been named the Glanville Formation by Firman (1966).

AGE OF SEDIMENTS

Immediately west of Ardrossan and Price Townships, the basal fluviatile sediments have been correlated by Crawford (1965) with the Middle to Upper Eocene portion of the Clinton Coal Measures in the northern side of the St. Vincent Basin. Although the fluviatile sediments in the lower portion of the Black Point well do not contain lignites which could be used for the purpose of palynological dating, these sediments are likely to be of Middle to Upper Eocene age as they underlie marine sediments of earliest Upper Eocene age.

The earliest Upper Eocene marine sediments of the Mulbowurtie Formation are found between 119 and 155 metres in the Black Point well. Their age is indicated by the first appearance (down the hole) of *Truncorotaloides collactea* Finlay at 119 metres. The absence of *Globoquadrina primitiva* Finlay (= *Truncorotaloides primitiva*) whose faunal range partly corresponds to that of *T. collactea*, elsewhere during the Middle Eocene (Ludbrook, 1967) suggests an early Upper Eocene age, as the range of *T. collactea* extends into the Upper Eocene. Although Ludbrook (1967, Fig. 3) included part of the Mulbowurtie Formation in the Middle Eocene, she has not published the evidence and Lindsay (1969) indicates that *T. primitiva* has not been found in the St. Vincent Basin. The Upper Eocene ranges of foraminifera associated with *T. collactea* in this well and within the interval 232 and 259 metres in the Troubridge well are shown in Figure 7. *Hantkenina alabamensis* which is a zonal fossil of the *H. alabamensis* zone (Glaessner, 1951; Faunal Unit 1 of Carter, 1958) has not been found in the wells, but only occasional specimens are reported from surface sections in the eastern side of the basin.

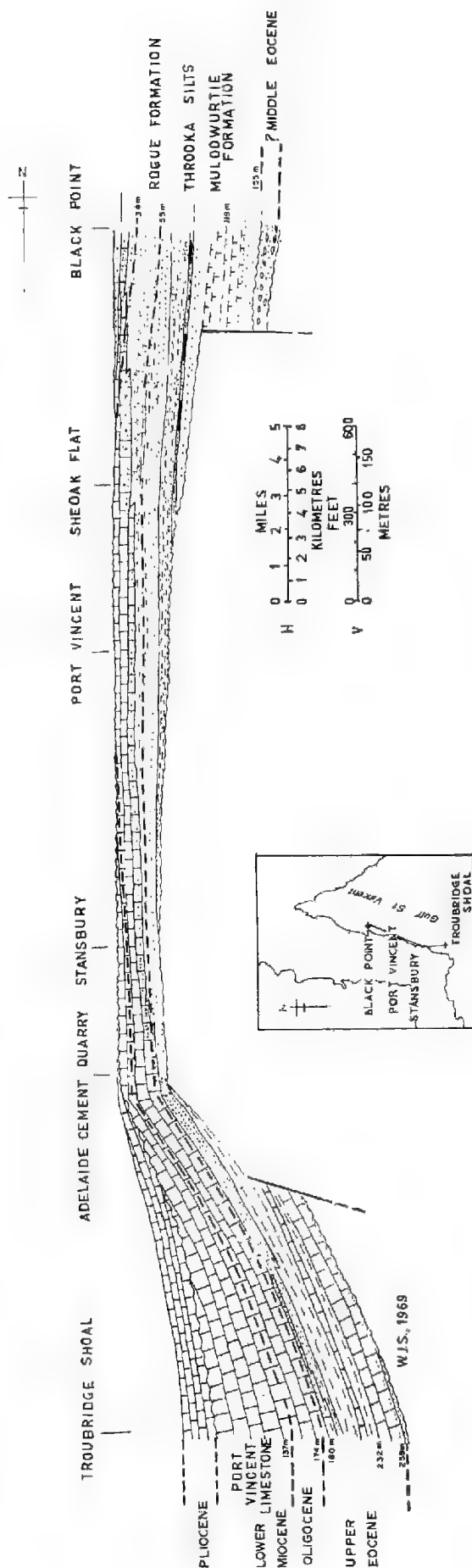
The earliest Upper Eocene marine sediments accumulated during the uppermost portion of the lower subzone of the *Turborotalia aculeata* zone, which was recognized by Ludbrook and Lindsay (1969). The remaining portion of this zone and the succeeding *Subbotina linaperta* zone which are present in the eastern side of the basin (Lindsay, 1969) can also be recognized in its western side (Fig. 7). Lindsay (1967; 1969) indicates that the upper boundaries of these zones are characterized by the final appearance of their zonal fossils. The lower boundary of the *T. aculeata* zone can not be recognized, as marine sediments of this age have not been deposited in this area.

In the Troubridge well the first occurrence (down the hole) of *S. linaperta* is found 12 metres above the base of the Port Vincent Limestones at 174 metres while *T. aculeata* was encountered at 180 metres. This suggests that the *S. linaperta* Zone is present in this bore. A clay and thin limestone sequence between 186 and 232 metres is included within the upper portion of the *T. aculeata* Zone. In the Black Point well (Fig. 4) *S. linaperta* is first recorded rarely at 55 metres in the Rogue Formation. This suggests that the remaining beds of the Mulbowurtie Formation, Throoka Silts and part of the Rogue Formation were deposited during this time interval. Planktonics are usually very rare in the upper part of this interval in well-sorted sands of the Rogue Formation which may explain the absence of *T. aculeata* in this portion of the Black Point well. The same formations were deposited within this time interval in their coastal sequences except most of the Rogue Formation is of definite Upper Eocene age at its type area. *Globigerapsis index* Finlay is found near the base of the formation whereas *S. linaperta* and *C. cubensis* are present about 6 metres below its top.

In coastal cliffs between Black Point and section 24 south of Port Vincent, the final appearances of both *S. cf. linaperta* and *T. aculeata* occur within the upper beds of the Rogue Formation. Although sample intervals for the purpose of this study are widely spaced *S. cf. linaperta* and *T. aculeata* occur together

CROSS-SECTION YORKE PENINSULA

Fig.6



about 1.5 metres above the Port Julia Greensand Member at section 15 (Fig. 3). Immediately south of section 16, *S. cf. linaperta* occurs without *T. aculeata* about 3 metres above this member.

Distinctive benthonic foraminifera noted by Carter (1958, 1964) in Victoria are also present in the western side of the basin (Glacssner and Wade, 1958). Wade (1964) recorded *Sherbornina atkinsoni*, *Asterigerina adelaidensis* and *Crespinina kingscotensis* within the Muloowurtie Formation located in the coastal area. In this area *Muslinella chapmani* and *Pseudopolymorphina sp.* (figured by Ludbrook, 1963) are also present within the lower half of this formation. In the Black Point well a similar assemblage occurs within most of the Muloowurtie Formation. In this bore and the coastal section the *Bolivina* sp. (figured by Ludbrook, 1963) and juvenile specimens of *Lamarckina cf. airensis* are also present. Benthonic foraminifera which extend throughout the Upper Eocene and are found in sediments of Oligocene age are shown in Figure 7. Near the top of the Muloowurtie Formation in both the subsurface and in the coastal area between Rogue Point and Harts Mine, foraminifera become very small and no diagnostic forms are present. The absence of diagnostic foraminifera in the strata may be due to regression that has taken place at different times within the upper half of the Muloowurtie Formation. On the other hand *A. adelaidensis* and *Pseudopolymorphina sp.* are not found above the lagoonal Throoka Silts in the basal beds of the Rogue Formation. From these considerations, the Muloowurtie Formation above 119 metres in the Black Point well and the coastal exposures probably correlate with the Banded Marl Member and possibly the lowermost beds of the Soft Marl Member of the Blanche Point Marls in the eastern side of the basin.

In the Troubridge well (Fig. 6), *A. adelaidensis* also occurs rarely above *T. collactea* in glauconitic calcareous clays between 197 and 212 metres. In this well *Pseudopolymorphina sp.* and *Lamarckina airensis* are found between 229 and 259 metres in a limestone sequence. Ludbrook (1963) and Lindsay (1967) have recorded this *Pseudopolymorphina sp.* only from sediments which were only deposited during the lower portion of the *T. aculeata* Zone. However in the Troubridge well this *Pseudopolymorphina sp.* is not present in calcareous clays between 213 and 229 metres but occurs at 210 metres in fine calcarenites which were deposited during the upper portion of the *T. aculeata* Zone. This indicates that the distribution of this foraminifer is probably controlled by sediment type.

L. cf. airensis occurs within the lower half of the Rogue Formation between Port Vincent and Black Point and in the Black Point well between 69 and 84 metres. In the Troubridge well the first probable occurrence of this foraminifer is at 95 metres in a clay sequence. Carter (1964) notes that the final appearance of *L. airensis* occurs within his Faunal Unit 2 which would also be close to the final appearance of this benthonic form in this area.

On the bases of benthonic : planktonic foraminifera and stratigraphic position within the range of diagnostic planktonics, the lagoonal Throoka Silts probably correlate with the lower part of the Soft Marl Member and equivalents on the eastern side of the basin. The sands near the middle of the Rogue Formation between Stansbury and Black Point are about time-equivalent to the uppermost beds of the Soft Marl Member, the Chinaman's Gully Beds and the lowermost portion of the Port Willunga Beds. While most of this sequence is regressive, its uppermost portion is considered transgressive, as shown by a similar sequence encountered in the Black Point well where it now underlies sediments of Oligocene age. In this well the uppermost portion of this sequence is an approximate time equivalent to the remaining sediments of Upper Eocene age in the Port Willunga Beds.

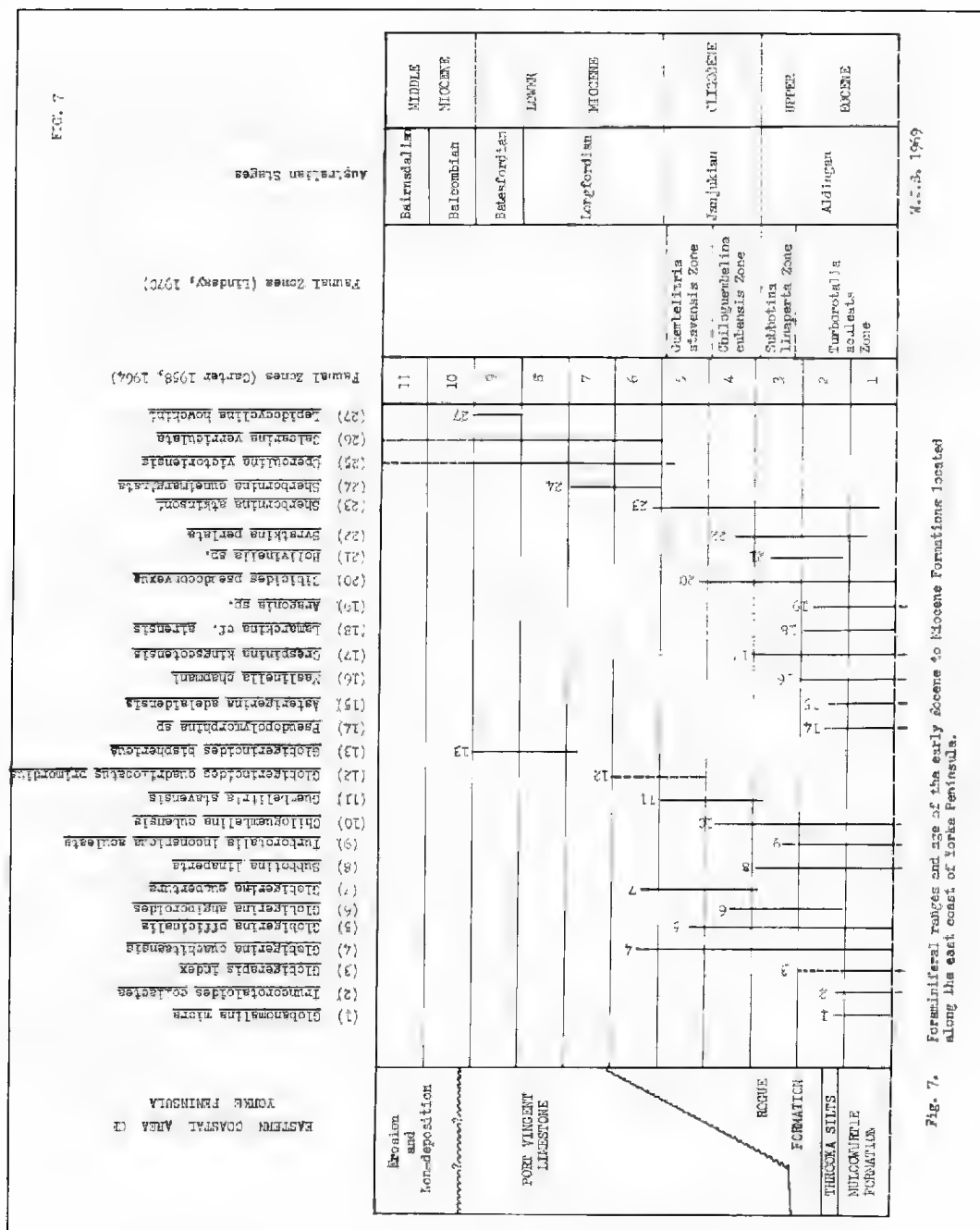
Lindsay (1967, 1969) has established three zones for faunas of Oligocene age in the eastern side of the St. Vincent Basin. The *Chiloguembelina cubensis* Zone and the *Guembelitra stavensis* Zone have been recognized (Fig. 7) within faunas in its western side, but the uppermost Oligocene *Globigerina euapertura* Zone has not been recorded here. This is probably due to widely spaced sampling and very thin sequences that could be of this age. Lindsay (1967) indicates that the lower boundary of *C. cubensis* Zone is characterized by the final appearance of *S. linaperta* while the upper boundaries of this zone and the succeeding *G. stavensis* Zone are defined by the final appearance of the zonal fossils (Fig. 7). The overlapping ranges of *Chiloguembelina* and *Guembelitra* were shown by Wade (1961, Table 1). The final appearance of *Guembelitra* is just below the Oligocene-Miocene boundary (Wade, 1964, Lindsay, 1967, 1968).

Between Black Point and Stansbury the *C. cubensis* Zone and the *G. stavensis* Zone are present within the uppermost beds of the Rogue Formation and the Port Vincent Limestone. In the Rogue Formation at sections 15 and 16 (Fig. 3) the local, final occurrence of *C. cubensis* is found about 5 metres below the top of the Rogue Formation. Immediately south of Sheoak Flat, it is now found just above the base of the Port Vincent Limestone about 120 metres north of section 22. The uppermost occurrence of this fossil north and south of Sheoak Flat suggests that the lowermost beds of the Port Vincent Limestone are about time-equivalent to the uppermost part of the Rogue Formation (Fig. 3). Further south at section 27 (Fig. 4), *C. cubensis* is present 1-7 metres above the base of the Port Vincent Limestone. At these localities, *G. euapertura*, *G. hulloides*, *G. ampliapertura*, *G. angustumbilicata* and *Guembelitra stavensis* and are associated with the zone fossil, *C. cubensis*.

Occasional specimens of *G. stavensis* are present in the remaining beds of the Rogue Formation and Port Vincent Limestone between Sheoak Flat and Black Point and the remaining outcrop of the Port Vincent Limestone immediately south of Sheoak Flat. Planktonics are usually very rare with only occasional specimens of *G. euapertura* and *G. ampliapertura*. Within these beds, *S. atkinsoni* and *Soratkina perlata* (Upper Eocene-Oligocene) accompany *G. stavensis* which suggests an Oligocene age (Fig. 7). The first appearance of the echinoid *Lovenia woodsi* is found within the *G. stavensis* Zone on both the eastern and western sides of this basin.

Between Port Vincent and Stansbury rare specimens of *Globigerinoides quadrilobus primordius* (Banner and Blow) are present within the *G. stavensis* Zone. It is only known from Carter's Faunal Units 5 and 6 (Wade, 1964; Table 1). Immediately south of Beach Point at section 18, *Operculina victoriensis* occurs within the upper third of the Port Vincent Limestone with re-crystallized *Sherbornina* while midway between sections 28 and 29, the uppermost beds of the Port Vincent Limestone contain *S. cuneimarginata*, *S. atkinsoni* and *O. victoriensis*. The assemblage of foraminifera (Faunal Unit 6, Fig. 7) suggests that the Oligocene-Miocene boundary is present within the Port Vincent Limestone at these localities. Further south at Klein Point, Ludbrook (1963) recorded *S. atkinsoni* near the base of coastal cliffs and *C. cuneimarginata* at a higher stratigraphic level within the Port Vincent Limestone. This suggests that the Oligocene-Miocene boundary is also present at this locality.

In the Troubridge well, the *C. cubensis* and *G. stavensis* Zones cannot be recognized within the Port Vincent Limestone because the zonal fossils are either very rare or absent. The lower boundary of Oligocene is tentatively placed at 174 metres where *S. linaperta* is first encountered down the bore hole (Fig. 6). From 168 to 174 metres, bryozoa limestones contain a similar assemblage of planktonics as those recorded in rocks of Oligocene age in the



coastal sequences (Fig. 7). Although planktonics are very rare or absent above 168 metres in the Troubridge well, occasional small specimens of *G. stauensis* only have been recorded from 159 to 165 metres. The Oligocene-Miocene boundary can be only tentatively placed between 137 and 159 metres in this well. The first appearance (down the hole) of the *S. atkinsoni* accompanied by *S. cuneimarginata* is at 137 metres but these are extremely rare. Bryozoal limestones at 146 metres containing *S. cuneimarginata*, *S. atkinsoni* and *C. verriculata* (all rare) may be close to the Oligocene-Miocene boundary.

In the Black Point well, quartz sands within the Rogue Formation between 34 and 55 metres are of Oligocene age (Fig. 1). The first appearance of *G. stauensis* is at 36 metres. Within this interval planktonic foraminifera in these sands are *G. ouachitaensis*, *G. angiporoides*, *G. bulloides* and *G. angustum-bilicatu*. *Cibicides pseudoconvexus* is found rarely near the base of this sequence whereas *S. atkinsoni* is present as high as 34 metres. *Calcarina verriculata* is present between 25 and 37 metres suggesting that the Oligocene-Miocene boundary occurs either within the uppermost sands of the Rogue Formation or within arenaceous bryozoal limestones (Port Vincent Limestone) at the top of the well. Single specimens of *C. verriculata* are recorded below 37 metres but their preservation suggests contamination.

Sediments of Oligocene age within the Port Vincent Limestone and the Rogue Formation are correlated with Oligocene sediments within the Port Willunga Beds in the eastern side of the basin.

Immediately south of Muloowurtie Point (Sect. 5b, Fig. 2), limestones containing the association of *S. atkinsoni*, *S. cuneimarginata* and *C. verriculata* are considered of Lower Miocene age (Faunal Unit 6). It has been previously shown that these limestones and thin basal sands unconformably overlie about 5 metres of beach sands constituting the uppermost beds of the Rogue Formation. The first fully marine bed just below these sands to the south contains *S. linaperta* and *C. cubensis*. This suggests that the faunas diagnostic of the *C. cubensis* Zone and *G. stauensis* Zone are not present at this locality.

Further south of Muloowurtie Point in the Black Point well the upper 3 metres of the Rogue Formation and lower 6 metres of the Port Vincent Limestone contain *C. verriculata*. *S. atkinsoni* is present near the top of the Rogue Formation whereas *S. cuneimarginata* occurs rarely in the Port Vincent Limestone of this well. The upper 9 metres of sediments in this well, limestones just south of Muloowurtie Point and the upper beds of the Port Vincent Limestone at localities immediately south of Beach Point are correlated with the Port Willunga Beds of lowermost Miocene age, i.e. Faunal Unit 6.

In the Troubridge well, Carter's Faunal Units 6 and part of 7 are probably present between 116 and 146 metres within the Port Vincent Limestone. *C. verriculata* and *O. victoriensis* occur within this interval whereas *S. atkinsoni* and *S. cuneimarginata* are found together in the lower 9 metres of this interval. Occasional specimens of *Gdes. bisphericus* occur between 97 and 122 metres. Limestones below 122 metres also contain this planktonic fauna but their preservation suggests contamination. *Lepidocyclus* within bryozoal limestones between 85 and 97 metres correlate with the lower portion of the Melton Limestone on the northern part of Yorke Peninsula. In this well, the interval from 85 to 146 metres within the Port Vincent Limestone are correlated with sediments of Lower Miocene age (Faunal Units 6, 7, 8 and part of 9) within the Port Willunga Beds on the eastern side of the basin. In the Troubridge well, the Lower Miocene-Middle Miocene boundary may be present in 24 metres of limestones above beds containing occasional *Lepidocyclus*, but there is no faunal evidence to prove this. On the other hand, sediments of Middle Miocene age occur in the

subsurface of the Adelaide Plains Embayment and the Melton area. Lindsay and Shepherd (1966) have shown that the Munno Para Clay Member of the Port Willunga Beds is of uppermost Batesfordian and lowermost Balcombian (parts of faunal Units 9 and 10). Lindsay (1970) has also indicated that the upper portion of the Melton Limestone is of lowermost Balcombian. The Balcombian is considered of Middle Miocene age (Carter, 1964; Wade, 1964 and Ludbrook, 1967). Lindsay (1968) also recognized sediments of Bairnsdalian age (Faunal Unit 11) from this area.

GEOLOGICAL HISTORY

Tertiary accumulation commenced in the northern area with the deposition of Middle Eocene fluvial sediments. Streams flowing from rising highs on the northwest portion of Yorke Peninsula transported fine and coarse detritus to sinking areas in the St. Vincent Basin.

Following the accumulation of these fluvial sediments, the ingression of the sea is documented by marine sediments (Muloowurtie Formation) deposited during the lower portion of the *Turborotalia aculeata* Zone representing earliest definite Upper Eocene age. The sea encroached onto the northern area of Yorke Peninsula, but did not extend onto its southerly coastal area. In the northern area, currents and/or wave-action tended to even the topography of the submarine floor by transport of sediment to areas of lower energy during subsidence. A shallowing of the sea is indicated by the Quartoo Sand Member of the Muloowurtie Formation, but since this portion of the formation was deposited over a great area of the depositional high between Pine Point and Harts Mine, basin expansion continued here. Slight deepening of the sea north of the depositional high is indicated by the upper beds of the Muloowurtie Formation while a high energy environment continued on its southern side.

The Upper Eocene sea uniformly retreated from the northern area and the region immediately offshore from the present coastline in the southern area. This is indicated by the lagoonal Throoka Silts and poorly fossiliferous arenaceous clays in the Troubridge well. After the accumulation of the lagoonal sediments, the Upper Eocene sea returned to present coastal areas and alternating clays and fairly well-sorted sandstones within the lower third of the Rogue Formation suggest an oscillating shoreline immediately west of the present coastline. High energy marine environments are documented by well-sorted quartz sandstone on the southern side of the depositional high and the area immediately south of Klein Point. Another retreat of the Upper Eocene sea, near the top of the *Turborotalia aculeata* Zone, is indicated by quartz sands in the middle portion of the Rogue Formation in the southern area, but the sea did not retreat past the present coastline as the sequence indicates a subsequent marine stillstand of short duration. During this time interval, there is no evidence within the Rogue Formation at Muloowurtie Point to suggest a retreat of the sea.

The sea probably retreated from the northern area during the *S. linaperta* Zone as suggested by the erosional surface separating Upper Eocene and Miocene strata. Non-deposition with minimal erosion probably took place during this hiatus because reworked foraminifera of Upper Eocene age have not been observed in sediments of Oligocene age in other areas. As the retreat of the sea continued in the northern area, a major advance of the sea had begun in the southern area. The sea continued to advance in this area during the Oligocene (*Chiloguembelina cubensis* and *Guembelina stansis* Zones) and Miocene time. Sedimentological and palaeoecological evidence from this area and other portions of the St. Vincent Basin, suggest that the sea during the latter zone

covered parts of the southern portion of Yorke Peninsula (Stuart, 1969). The facies relationships between the Rogue Formation and Port Vincent Limestone indicate a northerly component of this transgression (Fig. 6). The sea did not reach the vicinity of Muloowurtie Point until earliest Lower Miocene time as indicated by benthonic foraminifera within the Port Vincent Limestone. It is likely that by uppermost Lower Miocene time, the sea had covered most of Yorke Peninsula, as Miocene sediments (Melton Limestone and equivalents) are exposed in its northern portion, and slightly earlier limestones are present in the subsurface at Minlaton and upper Yorke Valley.

Available evidence in surface exposures and subsurface indicates a period of erosion which took place between the accumulation of lower Middle Miocene and Upper Pliocene sediments in Yorke Peninsula area. The Miocene sea had retreated from known areas of marine accumulation and probably from the remainder of the basin as well (Stuart, 1969).

During the Upper Pliocene the sea returned to parts of Yorke Peninsula and a narrow seaway was present on its southern portion (Ludbrook, 1959). Another erosional surface between Upper Pliocene marine strata and ?Pleistocene fluvatile sediments indicates another period of erosion. This was followed by the accumulation of fluvatile sediments along the east coast of Yorke Peninsula. A notable example of these are the fluvial-fan deposits ("Ardrossan Clay and Sandrock") deposited near Rogue Point (Fig. 2) and in the Ardrossan area (Tepper, 1879; Howchin, 1918). They were derived from basement and Tertiary rocks constituting low hills immediately to the west of the present coast (Crawford, 1965). These deposits and the remaining fluvatile sediments now exposed in the coastal cliffs of the southern area were weakly laterized and there is evidence particularly in the Ardrossan area of more than one soil profile. Green and red clays were laid down following still another period of erosion.

Sub-Recent shelly sediments accumulated in areas now constituting synclines of Tertiary strata, particularly on wave-cut platforms adjacent to townships in the southern area. Calcretes were formed in soil profiles during and after the climax of Pleistocene accumulation in the coastal area.

STRUCTURAL DEVELOPMENT

The study of Cainozoic strata along the east coast of Yorke Peninsula has done much to elucidate the structural history recorded here during the Cainozoic Era. Following the accumulation of fluvatile sediments in the vicinity of Black Point, the separation of a remnant of fluvatile sediments in the coastal sequence (Fig. 2) from those in the subsurface (Fig. 6) indicates that either north-south or northeast-southwest faulting occurred in this area prior to the deposition of earliest Upper Eocene marine sediments. The displacement of beds was less than 60 metres.

The accumulation of Tertiary sediments indicates that Yorke Peninsula can be sub-divided into blocks which are separated by linear elements (Fig. 1). However, it is apparent from the beds which form gentle synclines and anticlines that several minor fault-lines were active during times of more or less earth movement, so subdivisions into smaller blocks could be possible. Glaessner (1953) has previously shown that ancient faults (Sprigg, 1942) form the boundaries between areas of mild uplift and subsidence in areas east of the St. Vincent Gulf.

The northern block (A) appears to be separate from the southern areas, as indicated by the accumulation of the Upper Eocene Muloowurtie Formation. Slight tilting of this block towards the St. Vincent Gulf and to the north is indicated by the absence of these beds on the western side of Yorke Peninsula and

facies relationships of the high energy Quartoo Sand Member intertonguing with the main body of the Muloowurtie Formation in a northerly direction. The northward tilting of this block is also indicated by facies of mainly quartz sands in the Rogue Formation grading to more carbonate-rich rocks in a northerly direction.

South of Black Point the absence of the Muloowurtie Formation or equivalents from the east coast of Yorke Peninsula suggests that a north-south fault-line is present in this area. It is difficult to imagine an irregular topography persisting in such poorly indurated sediments as the Permian, throughout the Mesozoic and early Tertiary. This fault-line determined the boundary between more and less subsiding areas of accumulation. This explains the abnormal thickness of earliest Upper Eocene sediments under the western portion of the St. Vincent Gulf. This substantiates a statement by Crawford (1965) who considered that a fault-line was present in this area. The northern and southern blocks (A and B) acted as a single tectonic unit during the accumulation of the lower half of the Rogue Formation.

The independence of movement between blocks A and B is demonstrated by mild uplift of the northern block while the southern block was subsiding during at least the Oligocene. This is indicated by the unconformity between Upper Eocene and Miocene sediments in the northern area and the presence of Oligocene sediments in a conformable sequence in the southern area. Small pulses of variable subsidence took place during the accumulation of Oligocene sediments in the Rogue Formation between Port Julia and Port Vincent as suggested by facies relationships of quartz sands grading to clays. These facies relationships indicate that the variable rates of subsidence occurred adjacent to east-west fault-lines.

The tilting of the northern block and times of independence of the movements along the east coast of Yorke Peninsula suggest a southwest-northeast ancient fault-line located in the vicinity of Black Point (Fig. 1). This is also substantiated by aeromagnetic data (Schoenbarting, pers. comm.). This fault-line is also substantiated by a large synclinal structure between Rocky Point and Port Julia.

The two southern blocks (B and C) which form the lower portion of Yorke Peninsula have also undergone variable rates of movement. The southernmost block C (Fig. 1) was a persistent structural high during most of the Upper Eocene, sediments of this age are not present on this block. During the Oligocene, this block began to founder as remnants of rocks of this age are located there.

Thinner sequences of Oligocene and Miocene sediments accumulated on the landward side of the north-south fault-line adjacent to the east coast of Yorke Peninsula as shown by the transgressive Rogue Formation and Port Vincent Limestone. The northward component of this transgressive sequence (Fig. 6) also suggests that the relative rate of subsidence was greater parallel to and towards the present continental shelf; thus it is likely to be associated with larger scale epeirogenic earth movements.

Gentle folding movements occurred along the east coast of Yorke Peninsula between the accumulation of Miocene and Upper Pliocene sediments (Glaessner, 1953). The strata in several areas have also been faulted, but the displacements of beds are very small (Figs. 2, 3). However, the folding movements of the Cainozoic beds are dependent upon the movements of linear elements within Cambrian and basement rocks as are also the faulted beds.

Reactivated folding movements involved Pliocene beds as can be seen immediately south of Shoak Flat (Fig. 3). Between Stansbury and Giles Point (Fig. 1; Chart 3D shown by Stuart, 1969), a southward component of tilting movements can be recognized by unconformable relationships between Miocene,

Upper Pliocene, and Pleistocene beds and also between beds of Pleistocene age (Stuart, 1969). In the Ardrossan area, fluvial-fan deposits also indicate earth movements along linear elements.

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QUONDONG STATION, SOUTH AUSTRALIA: A FIELD CONTEXT FOR APPLIED RANGELAND RESEARCH

*BY SUSAN BARKER**

Summary

Sheep stations are the administrative units of the arid zone pastoral industry in southern South Australia. Their general nature, history and present circumstances are given, with particular regard for the native vegetation upon which their productivity depends, by using Quondong Station as an example. A study of the pastures of Quondong Station is presented, intended as a general field context to which research results may be related.

The flora of Quondong Station is listed. The native pastures are classified initially into four main groups, and are then cross-classified on other features. Results are summarised in map form.

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INTRODUCTION

In recent years concerted efforts have been directed towards ecological problems associated with the arid zone pastoral industry in South Australia. Much of the research is still in progress, but some is already published (Lange, 1969; Barker and Lange, 1969a). Such papers are specialised, and it is necessary to describe the field context within which specialised advances must be interpreted.

When sheep were introduced to arid Australia in the nineteenth century, their impact on the native shrubs was both sudden and disastrous. For example, Dixon (1880) and Woolls (1882) describe the destruction of saltbush after only a few decades of grazing in western New South Wales. Arid zone shrubs are slow growing, long lived plants adapted to low rainfalls and slow nutrient cycling. As such, they are quite different from kinds of plants that evolved under intensive grazing by ungulates. While climatic changes can gradually degrade arid zone vegetation for periods, the effect of hooved grazing animals on these vulnerable populations has had an inordinately destructive effect for such a short time span.

Pioneers were concerned with expansion and development in the short term, rather than conservation in the long term. This attitude can be understood when one recalls the colonists' ignorance about the Australian environment (Meinig, 1963).

At the present time, disregard for long term conservation can no longer be tolerated. It is imperative for the future of this State that the consequences of the pastoral industry be examined. The type of resource being used by the pastoral industry is described by reference to a single administrative unit, Quondong Station, where grazing has been more or less continuous since 1873. The situation here is similar to that on many sheep stations in this and other States; boundary fences cut across different vegetation, rock and soil types, and paddock size and shape is determined by the disposition of a limited number of stock water points, often having little relation to use of different pasture types. Under such conditions it is inevitable that, given free range over several square miles, stock will utilise and, in extreme cases, degrade certain types of vegetation more than others.

In addition to the description of the current situation on Quondong Station, the history of the area is outlined to indicate how historical factors may have had an effect on the present pasture pattern.

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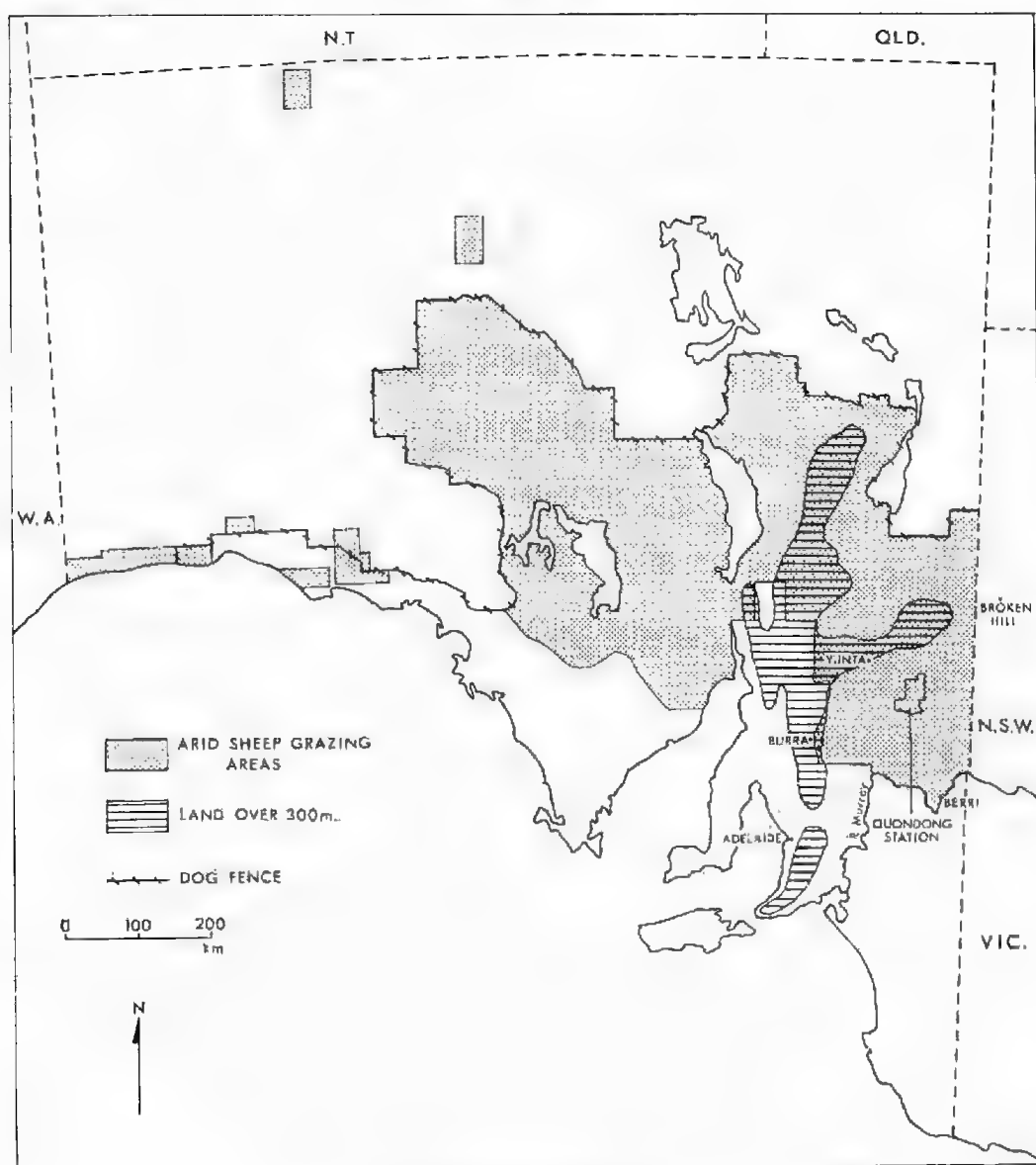


Fig. 1. Locality diagram.

SITUATION AND ENVIRONMENT

Quondong Station, covering an area of approximately 830 sq km, lies in the northern part of the Murray basin, south east of the Olary Spur, and almost equidistant between Burra and Broken Hill (Fig. 1). The over-riding climatic feature of this area is the low rainfall, the average for the period 1955-1968 being 180 mm (Table 1). The occurrence of rain is most erratic, more so, for instance, than in the coastal arid areas of the State (Commonwealth Bureau of Meteorology, 1961). Although the figures are variable, it appears that on average most rain is received in May and least in October.

TABLE 1
Rainfall at Quondong, in mm
(by courtesy of the Pastoral Board)

	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1955	0.0	87.1	44.5	7.9	63.5	38.1	1.0	21.1	28.2	6.9	16.8	1.0	316.1
1956	0.0	0.0	62.0	19.6	33.0	16.0	37.3	4.3	19.8	9.7	13.5	0.0	216.2
1957	0.0	64.0	5.1	0.0	4.3	68.6	1.0	17.8	4.6	16.3	3.8	24.4	209.9
1958													
1959	1.3	13.0	23.6	0.0	11.9	0.0	14.2	7.9	4.3	28.2	0.0	8.4	112.8
1960	4.3	7.1	5.8	13.5	19.1	3.3	38.6	14.2	28.7	0.0	35.3	0.0	169.9
1961	0.0	11.9	1.3	27.7	5.6	0.0	6.6	12.5	17.0	1.3	64.8	29.2	177.9
1962	59.2	0.0	22.4	0.0	32.5	6.6	2.3	15.8	0.0	7.9	0.0	70.9	217.6
1963	39.6	0.0	0.8	22.4	45.2	41.7	21.8	16.8	0.0	12.7	2.5	11.7	215.7
1964	10.8	0.0	0.0	12.2	7.4	5.3	0.0	15.2	81.5	0.8	1.8	18.0	153.0
1965	0.0	—	—	0.0	3.8	13.2	15.5	13.7	16.8	0.0	7.1	27.2	97.3
1966	8.1	19.8	8.1	0.0	16.0	11.7	7.1	0.0	11.9	9.1	15.2	44.2	151.2
1967	8.1	36.3	4.8	0.0	4.1	2.8	2.8	16.8	6.1	0.0	0.0	0.0	81.8
1968	61.0	9.9	8.4	27.2	27.2	26.7	30.7	15.2	0.0	5.3	0.0	6.4	218.0
Mean	14.8	18.5	14.5	10.0	21.5	18.0	13.7	13.2	16.9	7.6	12.4	18.6	179.7

Records of wind direction are available for Yunta and these display conditions generally applicable to the plains lying east. During the warmer months the prevailing winds are from the southerly quarter, whereas in winter, winds are more frequent from the north west (Table 2).

TABLE 2
% Frequency of Wind Direction at Yunta at 900 hr
(by courtesy of the Bureau of Meteorology)

YUNTA 1962-63													
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
N	3	9	3	2	1	7	2	3	7	3	10	12	
NE	14	7	2	5	10	8	3	3	3	10	17	7	
E	2	1	0	2	0	0	2	0	1	0	2	0	
SE	45	54	54	30	20	2	8	11	27	34	24	51	
S	0	0	3	3	5	0	2	3	2	3	7	6	
SW	13	18	17	25	20	17	18	18	27	24	26	12	
W	2	0	0	0	5	5	3	8	5	3	0	0	
NW	16	9	13	14	24	32	38	36	25	18	12	7	
CALMS	5	2	8	19	15	29	24	18	3	5	2	5	

Temperature data are shown in Table 3; the hottest months, January and February, achieve maxima of 32°C and the coolest months, June and July, 16°C and 14°C respectively. Extreme maxima and minima indicate the range of temperature which can be experienced by the region.

Such meagre meteorological information is typical for most sheep stations.

The geology of the area is imperfectly known (O'Driscoll, 1960; Ludbrook, 1961). Proterozoic and Palaeozoic basement rocks outcrop in the Mount lofty Ranges and the Olary Spur forming a rim to the north of the Murray Basin. Quondong is about 52 km to the south-east of this outcrop and is situated on the

TABLE 3
Temperature in °C for Yunta
(by courtesy of the Bureau of Meteorology)

YUNTA

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Av. Max.	32.2	32.2	28.0	23.3	19.4	16.1	14.1	10.4	18.9	22.8	28.0	28.9
Av. Min.	14.1	14.4	12.0	8.3	5.6	3.3	2.8	4.2	5.0	8.3	11.2	13.2
Av. Mean	23.3	23.3	20.0	16.1	12.5	10.0	8.3	10.0	12.2	15.6	19.7	20.6
Extreme Max.	46.1	43.3	40.6	33.9	27.8	23.9	22.8	28.3	98.0	40.0	42.2	47.9
1951-65 Date	2/'60	28/'65	18/'65	2/'54	1/'58	19/'60	27/'60	11/'59	29/'65	20/'65	30/'62	19/'65
Extreme Min.	6.7	4.4	1.3	1.1	-3.9	-6.7	-6.7	-5.0	-3.1	1.0	1.1	1.8
1951-65 Date	1/'56	29/'58	22/'56	15/'63	24/'57	17/'59	9+10/'59	8/'62	27/'53	4/'63	3/'65	11/'52

infill material of the Basin, consisting of Tertiary and post-Tertiary littoral, marine and freshwater sediments, which in turn have been overlain by Recent aeolian deposits (O'Driscoll, 1960; Firman, 1965). This lack of geological information is not general, however, and for sheep stations situated where there are major rock outcrops, the information available is as good as that for the wetter parts of the State.

There is little detail in the literature concerning the relief of the area and the following new observations are presented. The general elevation falls 78 m in a south-easterly direction from the north of Ki-Ki Paddock, to the south-east corner of Drayton Paddock. Topographically the station may be divided into two regions north and south of a line which joins points A and B in Fig. 2. The principal ridges and drainage lines also shown in Fig. 2 have heights relative to each other varying between 1 m and 7 m.

To the north, the country is a gently undulating outwash plain of the Olary Spur, traversed by broad ill-defined watercourses or washes, the intervening areas being occupied by low calcareous ridges and Recent sand dunes. There are two main drainage systems in this region; one flows from north to south in Record, Sixty, Sergeant's, Well, Ki-Ki and Eighty paddocks and the other flows from west to east through Sergeant's and Swamp paddocks. The two systems mingle and lose their identity in George's and the Boundary paddocks. Only in the watercourse running through Ki-Ki and Eighty paddocks has gully erosion proceeded to the extent that parts of it could be regarded as a creek, with banks and a flat sandy bed (Pl. 1a). It is probable that this has occurred subsequent to sheep being depastured in the area, as a result of increased run-off due to compaction. This phenomenon has been observed elsewhere (Jackson, 1958).

The ridges, which are old dunes, have solonised soils, containing a high proportion of calcium carbonate both in the A horizon and in the lower layers, where nodular or massive calcrete occurs. This soil type is classified as Gel. 12, according to the Factual Key (Northcote, 1965). The occurrence of polygonal patterned ground in these soils has been reported previously (Barker and Lange, 1969b).

South of the line A—B the ridges and dunes are more numerous and the broad alluvial expanses of watercourses are absent. The drainage lines are relatively small and are radial, draining into claypans and other low-lying areas.

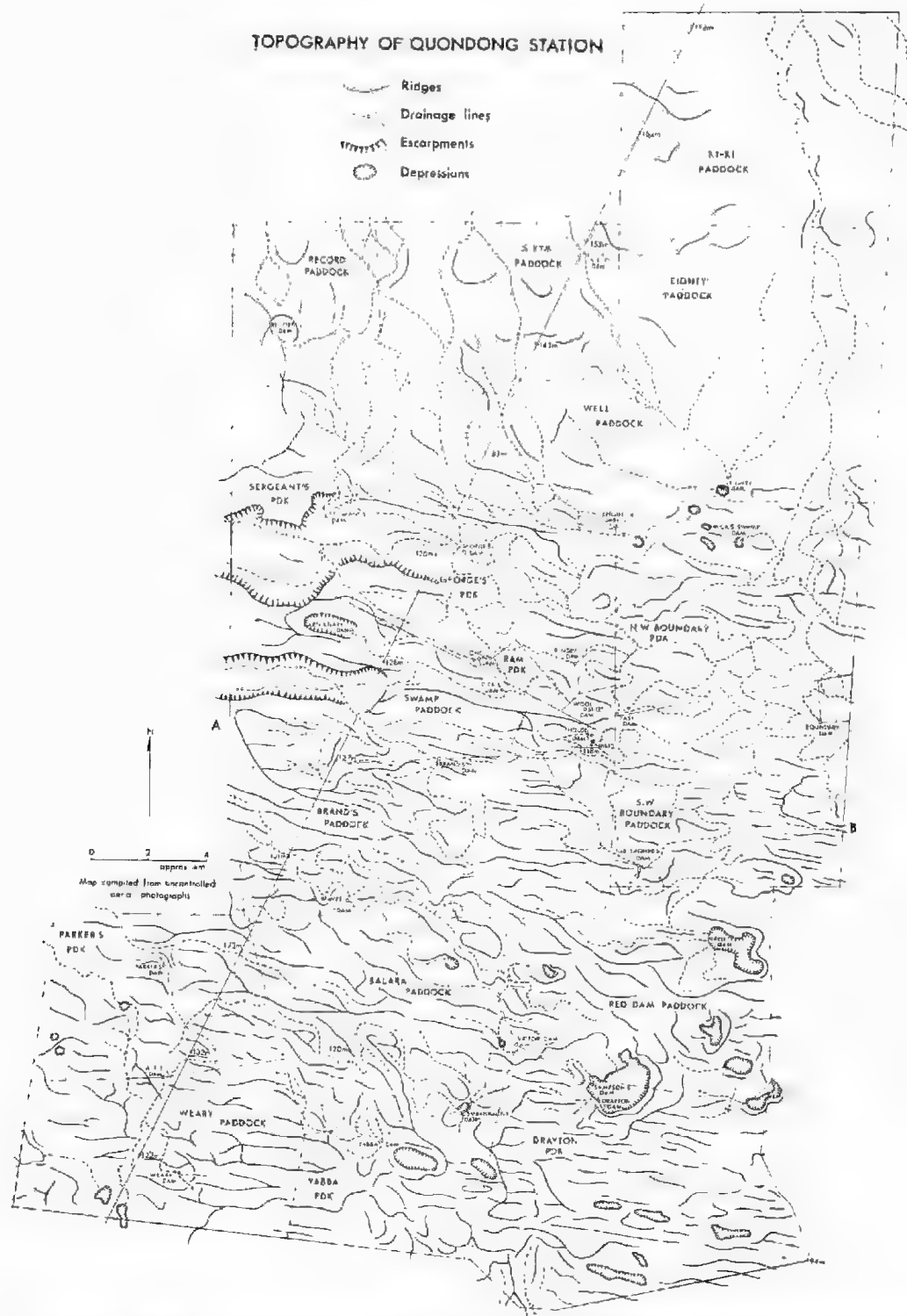


Fig. 2. Map of Quondong Station, showing principal topographic features and bench mark heights.

Some of the claypans have lunettes along their eastern margins. These may be an indication of a higher rainfall regime in the Recent past, as lunettes are apparently formed by a combination of wave action on lake shores during wet winter months and deflation from dry lake beds during the summer (Campbell, 1968). The current rainfall would be insufficient for water to lie in the Quondong claypans for any length of time.

The far south east of the station is occupied by a continuous area (some 25-30 sq km) of deep sandy dunes of Recent aeolian origin, oriented in an east-west direction. They can be recognised from the vegetation map by the occurrence of mallee; isolated sand dunes appear as far north as the Well paddock. These have soils classified as Uc5. 11.

Descriptions by O'Driscoll (1960) of the hydrology of the north of the Murray Basin are based on information from a few bores. The salinities of the fossil waters examined on Quondong are too high to allow for their use as stock water. All stock water is, therefore, derived from surface run-off stored in earth dams. The position of these in relation to the topography is shown in Fig. 2. All the dams are watering points for stock, and some of their water is piped to troughs in parts of the station which would otherwise be ungrazed.

The preceding account emphasises that a sheep station is not homogeneous in terms of landscape. Design of experiments in such a variable situation is thus difficult; also, extrapolation of findings from one region to another must be at the level of principal rather than detail.

VEGETATION

Over a period of one year, March 1967—April 1968, plant collections were made on Quondong. These collections, consisting of some 150 species, are now housed in the State Herbarium of South Australia. Subsequent experience on other stations with a herbaceous rather than a shrub vegetation has shown that plant collections often cannot be completed for several years.

The map at the end of this paper assembles and displays the outcome of the work upon which this paper is based. Sixty extensive ground traverses were needed to rectify adequately an initial interpretation based on aerial photographs. The classification thought best suited for analysis of the system was one using character trees first, then cross-classifying successively in terms of character shrubs, then herbaceous components. This kind of classification avoids the necessity to draw discrete boundaries as between two mutually exclusive classes, and permits mapping which expresses gradients of change.

Details concerning the map are given with the explanatory legend accompanying the map.

Compared with some stations the broad vegetation pattern is simple on account of the comparative geologic and topographic uniformity. There are four principal vegetation types. These are (I) *Casuarina cristata* (black oak) woodland (II) Mallee (III) *Gallitris columellaris* woodland (IV) *Acacia aneura* (mulga) woodland. In addition, section (V) includes a miscellany of local but distinctive vegetation types characteristic of water-collecting areas other than the major watercourses or washes.

(I) *Casuarina cristata* (black oak) woodland, found on the old calcareous dune ridges north and south of the line A—B, occupies by far the greatest area of the station and is extremely dense in parts, particularly in the south. Although many groves of this tree are dead, especially in George's paddock, it is regenerating freely by means of suckers all over the station, even in apparently dead stands (Pl. 1b). This is of interest as workers in other parts of the State (Hall, Specht and Eardley, 1964; R. M. Purdie—personal communication) imply that

under heavy stocking or in times of drought *Casuarina* suckers are grazed down before they can reach maturity.

Other tree species found commonly throughout this woodland are *Myoporum platycarpum*, freely regenerating from seed (Pl. 1c), contrary to observations by Hall *et al.* at Koonamore, and *Heterodendrum oleaeifolium*, the regenerating suckers of which are grazed down as in other parts of the State (Hall *et al.*, 1964; R. M. Purdie—personal communication).

Eremophila longifolia (emu bush), *Acacia osicoides*, *Pittosporum phylliraeoides* (native willow, apricot), and *Santalum acuminatum* (quondong) are rather less common.

The shrub layer consists principally of *Kochia sedifolia* (bluebush) with *K. excavata* var. *trichoptera* and *Bassia diacantha*. On the tops of the calcareous ridges there is often very little else, but other shrubs fairly common locally are *Ptilotus obovatus*, *Olearia muelleri*, *Scaevola spinescens*, *Cratystylis conocephala*, *Cassia nemophila* var. *nemophila*, *C. nemophila* var. *coriacea*, *Acacia colletioides* and *Templetonia egena* (desert broombush), with *Kochia brevifolia*, *K. georgei*, *K. astrotricha*, *Lycium australe* (boxthorn), *Nitraria schoberi* (nitrebush), *Eremophila glabra* (tar bush), *E. scoparia* and *Zygophyllum aurantiacum* less common.

C. nemophila var. *zygophylla*, *C. nemophila* var. *platypoda*, *Acacia hakeoides* and *Ptilotus atriplicifolius* are rare.

Atriplex vesicaria (bladder saltbush) occurs only in small quantities; an apparently isolated area in Ki-Ki paddock is the southernmost extension of saltbush from the floodplains of the Olary Spur on the adjacent Lilydale Station. Elsewhere on Quondong, *A. vesicaria* is associated with low lying areas in the south.

Kochia pyramidata, recognised as a symptom of degraded arid pastures in the north-west of the State (Jessup, 1948; Correll, 1967), does not occur extensively on Quondong Station.

Rhagodia spinescens var. *deltophylla*, *Rh. nutans* and *Enchylaena tomentosa* are found throughout the *Casuarina* woodland, but mainly under trees and in drainage lines.

(II) The mallees, *Eucalyptus oleosa* and *E. gracilis* on the dunes in Drayton paddock, a northern extension of the Murray Mallee, have a sparse shrub understorey. *Triodia irritans* (porcupine grass) provides most of the ground cover; further north there is less porcupine grass and shrubs are present, including *Chenopodium desertorum*, *Grevillea huegghii*, *Hakea leucoptera*, *Olearia pime-lioides*, *Kochia triptera* var. *eriodada* and *K. sedifolia*, and the herb *Boerhavia diffusa*. In places the mallee intergrades with dunes carrying *Casuarina cristata* and *Hakea leucoptera*, with *Kochia tomentosa* and *K. triptera* var. *eriodada*.

(III) In two small areas of the station sand dunes are occupied by *Cullitris columellaris*, with *Hakea leucoptera*, *Kochia brevifolia*, *K. triptera* var. *eriodada* and the grass *Eragrostis laniflora* in the understorey.

(IV) *Acacia aneura* (mulga) stands are in the drainage lines and watercourses which dissect the *Casuarina* woodland in the northern half of the station. Timber is much less dense in these areas and in the well defined watercourse of Ki-Ki and Eighty paddocks includes *Acacia victoriae* as well as other tree species mentioned in the description of the black oak woodland. Shrubs and forbs in these areas are

Eremophila maculata
(native fuchsia)
E. oppositifolia
Bassia paradoxa

Atriplex limbata
A. spongiosa
A. angulata
A. lindleyi

<i>A. acutibractea</i>	<i>Senecio magnificus</i>
<i>Solanum esuriale</i>	<i>Pterocaulon sphacelatum</i>
<i>Acacia burkittii</i>	<i>Hibiscus krichauffianus</i>
<i>Cassia nemophila</i> var. <i>nemophila</i>	<i>H. farragei</i>
<i>C. nemophila</i> var. <i>coriacea</i>	<i>Sida intricata</i>
<i>Suaresonia viridis</i>	<i>S. corrugata</i>
<i>Ixiolaena leptolepis</i>	<i>S. corrugata</i> var. <i>angustifolia</i>
<i>Erodiophyllum elderi</i>	
(Koonamore daisy)	

Herbaceous plants found in watercourses and wash areas are

<i>Stipa nitida</i>	<i>Brachyscome ciliaris</i>
<i>Cymbopogon exaltatus</i>	<i>Helipterum floribundum</i>
<i>Eragrostis dielsii</i>	<i>Calotis hispidula</i>
<i>E. setifolia</i>	<i>Nicotiana goodspeedii</i>
<i>Chloris acicularis</i>	<i>Convolvulus erubescens</i>
<i>Enneapogon avenaceus</i>	<i>Goodenia subintegra</i>
<i>E. cylindricus</i>	<i>Chenopodium pumilio</i>
<i>Panicum effusum</i>	<i>Arabidella trisecta</i>
<i>Danthonia</i> sp.	<i>Malvastrum spicatum</i>
<i>Vittadinia triloba</i>	<i>Morgania glabra</i>

(V) Although many of the above watercourse species occur along tracks, in sinkholes, drains and in the vicinity of dams, others are quite specific to sinkholes and similar small depressions—

<i>Gilesia biniflora</i>	<i>Marsilea drummondii</i> (nardoo)
<i>Alyssum linifolium</i>	<i>Eriochlamys behrii</i>
<i>Teucrium racemosum</i>	<i>Centipeda thespidioides</i>
<i>Euphorbia eremophila</i>	<i>Abutilon malvifolium</i>
<i>Oxalis corniculata</i>	

while some are specific to areas around dams and the drains leading into them, for example,

<i>Centaurium spicatum</i>	<i>Minuria leptophylla</i>
<i>Glinus lotoides</i>	<i>Atriplex eardleyi</i>
<i>Gnaphalium luteo-album</i>	<i>A. spongiosa</i>
<i>Tetragonia tetragonoides</i>	<i>Babbagia acroptera</i>
(native spinach)	<i>Bassia brachyptera</i>
<i>Portulaca oleracea</i>	<i>Tribulus terrestris</i>
<i>Verbena officinalis</i>	<i>Plantago varia.</i>

In addition, alien weeds are to be found only in watercourses and other water-collecting areas:

<i>Xanthium spinosum</i>	<i>Asphodelus fistulosus</i>
(Bathurst burr)	(wild onion)
<i>Salvia lanigera</i>	<i>Sida leprosa</i> var. <i>hederacea</i>
<i>Inula graveolens</i> (stinkwort)	<i>Diplotaxis tenuifolia</i>
<i>Nicotiana glauca</i> (tobacco bush)	<i>Heliotropium supinum</i>
<i>Centaurea melitensis</i>	<i>H. europaeum</i>
<i>Citrullus lanatus</i>	<i>Polygonum aviculare</i>
(bitter melon)	<i>Chenopodium murale.</i>
<i>Cucumis myriocarpus</i>	
(paddy melon)	

These are obviously very dependent on additional water for survival and are unlikely to spread to drier sites.

Swamps near Centenary Dam and Mick's Swamp Dam are characterised by *Muehlenbeckia cunninghamii* (lignum), *Chenopodium nitrariaceum* and *Eragrostis australasica* (canegrass), while parts of the southern clay pans have *Disphyma australe* (pigface) and *Pachyornis* sp. growing on them.

GRAZING HISTORY

Early pastoralists in South Australia relied upon supplies of natural surface water for stock, with the result that grazing in arid country began in the Flinders Ranges and Olary Spur. The northern part of the Murray Basin was without surface water (S. Aust. Parl. Paper No. 57, 1885-86), so this region was not opened up until the 1870's.

The present Quondong Station was originally three administrative units; a run known as Quondong Vale (including Brands paddock, S.W. Boundary paddock and all paddocks to the north of these), part of the Drayton Run (now Red Dam and Drayton paddocks) and part of the Pine Valley Run (Balara, Yabba, Weary, and Parker's paddocks).

Although the lease of Quondong Vale was first acquired in 1873, it is unlikely that any grazing occurred during the first few years as there would be no permanent water until 1876 when a Woolshed Dam in the south of George's paddock was dug. A further seven dams had been dug by 1880 and eight more and the Engine Well were complete by 1890; if sufficient rain had fallen during this period to fill the dams, then considerable areas would have become available for grazing.

The watercourse or wash country close to the homestead in George's, Swamp, Brand's and the Boundary paddocks, which were fenced prior to 1884, was probably the only area in constant use for shepherding sheep up to 1896. The surveyor described this area as "fair pasture; open country covered with various bushes and bluebush plains with a little grass, greater part heavily timbered with black oak etc." There is evidence that in the country north of this (now Sixty, Record, Eighty and Ki-Ki paddocks) the lessee had difficulty in establishing dams; also as the vegetation was described as heavily timbered with only a few open bluebush, plains, it was probably only lightly grazed, if at all.

It is apparent from correspondence with the Surveyor General's Office that the lessee had other problems. By 1890 the north of the Murray Basin was over-run by rabbits and dingoes (see also S. Aust. Parl. Paper No. 33, 1891) and by 1892 was drought stricken. No rain had been received for twelve months and leases to the south had been abandoned. Although the lessee said he would not restock the country as his lease was about to expire in 1894, he continued to run sheep until 1896, when he finally abandoned the country. He had 340 sheep watering on the Engine Well at that time in a vain attempt to convince the Government Analyst that the water was not too saline for stock. It may be this event which accounts for the effect seen in Pl. 1d where close to the Engine Well, George's paddock is denuded of bluebush.

Less is known about the Drayton and Pine Valley runs; as these two leases were taken out together in 1874 by the same person they were presumably run as a single unit. This area corresponds to the southern topographic region. The surveyor described it as "Poor pasture; undulating; light red sandy loam with occasional clay flats, limestone rubble on the surface. . . dense black oak, mallee, sandalwood, and various bushes, undergrowth and salthush." Six dams and a well were dug by 1890. Embankment Dam was the first and shepherding was certainly

carried on there in the nineteenth century. Weary Dam, dug in 1881, was used to water bullock teams crossing from New South Wales to Burra. As the pasture was assessed as being poorer than that further north, sheep on the Drayton-Pine Valley Run would have been more susceptible to the drought prevailing by 1891, leading to the abandonment of parts of it only 17 years after the lease was first taken up.

It seems reasonable to assume that the northern part of Quondong Station (Quondong Vale) was more heavily grazed during the nineteenth century than the southern part (Drayton—Pine Valley). Whatever the actual stock numbers may have been in these two areas, it seems certain from Goyder's remarks (S. Aust. Parl. Paper No. 82, 1867) that the practice of shepherding was far more destructive than the present one of allowing sheep to range freely within paddocks.

Between 1901 and 1909 one lessee acquired the leases described above now comprising Quondong Station; since then six more dams have been dug and more paddocks fenced, thus allowing more extensive use of pasture. The regular use of the country for sheep grazing probably dates from about 1910. Information in the Department of Lands indicates that the heavier use of the watercourse country to the north of the homestead continued for at least some of the past 60 years, the Drayton—Pine Valley section being referred to on one occasion as showing no sign of erosion or overstocking, as water supplies were too small to permit that, whereas there are implications that some of the watercourse paddocks had been overstocked.

Historical records for other stations are certainly more complete, particularly where the lease has been held by one family for several generations. Although the present manager of Quondong is interested in the station's history, the lease has been previously held by several others and records have been mislaid or destroyed. It would be of immense value in long term assessment of arid pasture conditions if all station records, including rainfall data, numbers of stock carried, photographs, could be maintained in Pastoral Archives.

DISCUSSION

Some of the effects of using arid vegetation as sheep pasture are beginning to be understood. The break up of the soil surface and destruction of a lichen crust, immediately lays the soil open to erosion by wind and water even where vegetation remains. Nutrients are removed with the top layers of soil. It has been suggested by Correll (1967) that the loss of nitrogen in this way has encouraged the change from *Kochia sedifolia* to *K. pyramidata* shrubland north-west of Port Augusta. While the surface layers may be pulverised, lower soil layers round water points and along sheep pads become highly compacted, promoting run-off, and allowing subsequent storage of water in dams, which would otherwise enter the soil (Jackson, 1958).

Such physical changes as these are clear within a short period of time and are now, therefore, predictable for all sheep grazing areas. However, the longevity of arid zone plants (Correll and Lange, 1966; R. M. Purdie—personal communication) means that changes in vegetation (apart from its complete removal in overstocked situations) will be much slower to appear, and consequently with our present state of knowledge, much less predictable. Not only does arid vegetation vary all over the State according to environmental differences, but even on one station the vegetation pattern will differ from paddock to paddock and within individual paddocks. The position of water points in paddocks will obviously affect the utilisation of these different pasture types, for it is well known that sheep degrade vegetation close to water before that in other parts of

paddocks (Osborn, Wood and Paltridge, 1932; Barker and Lange, 1969a). Sheep grazing habits are not yet fully understood, but general observations indicate that sheep preferentially graze watercourse vegetation and tend to graze into the wind along the southern edges of paddocks.

The uniform use of pasture is made very difficult in areas where paddock size and shape is strictly controlled (as at Quondong) by the number of suitable catchments for dams and the water-holding capacity of the substrates. In other arid areas of South Australia plentiful bore water and piped river water allow strategic positioning of troughs in small paddocks, thus encouraging stock to utilise pasture they might otherwise ignore.

The descriptions and comparisons made in this paper exemplify the multi-variate situation which arid rangeland ecologists have to understand before changes in the vegetation can be attributed to stocking. The overall vegetation pattern on Quondong Station is similar to that in the immediately surrounding areas of the Murray Basin, but differs from that found elsewhere in arid South Australia. It must, therefore, be understood that plants which may indicate degeneration in one part of the State do not necessarily indicate degeneration in other areas. This raises an important point. Results or observations gained from one location in the arid zone must not be extrapolated injudiciously. For example, comments made by Hall, Specht and Eardley (1964) on the regeneration of *Casuarina cristata* and *Myoporum platycarpum* at Koonamore, and by Jessup (1948) on the spread of *Kochia pyramidata* in overstocked situations in the north west, are at variance with observations made on Quondong. Generalisations made on the basis of particular results have introduced a great number of misleading statements into the literature.

A modern approach to the solution of management problems associated with natural ecological systems like these native arid pastures is to use simulation studies. These depend on the definition of parameters which describe the various aspects of the total system. At present it is difficult to see how precise parameters can be derived for such extremely variable vegetation.

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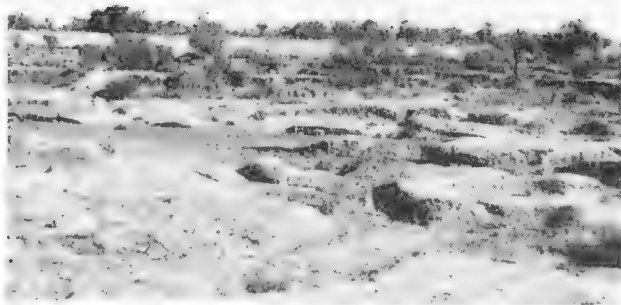
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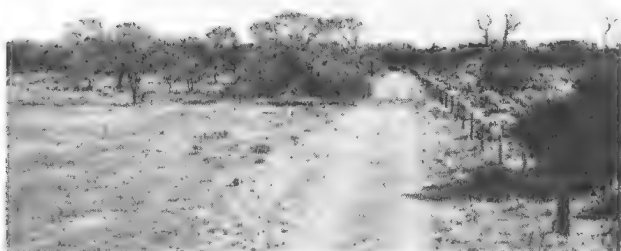
(a)



(b)



(c)



(d)

EXPLANATION OF PLATES

Top left—(a) Gully erosion in the Ki-Ki paddock watercourse.

Above—(b) *Casuarina cristata* suckering from apparently dead parent.

Centre left—(c) Young *Myoporum platycarpum* trees regenerated from seed.

Bottom left—(d) View looking west along fence between Well paddock (on right) and George's paddock.

A REVIEW OF THE PRECAMBRIAN AND LOWER PALAEOZOIC TECTONICS OF SOUTH AUSTRALIA

BY B. P. THOMSON*

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1. *Northwest.* Archaean fold belts of Yilgarn Block are apparently reflected in South Australia by the trends of the continental margin and the north east flank of the Adelaide Geosyncline.
2. *Northeast.* The Carpentarian and Adelaidean Fraser-Musgrave fold belt and crystalline basement in South Australia e.g. Gawler Craton.
3. *Northerly.* Adelaide Geosyncline and Torrens Hinge Zone, which is part of a meridional transcontinental structure.
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INTRODUCTION

This paper presents a review and tectonic interpretation of geological and other relevant data in South Australia and adjoining regions.

During the last three years the writer has been a member of the tectonic map Committee of the Geological Society of Australia which is engaged in the compilation of a new 1:5,000,000 scale tectonic map of Australia. This paper discusses some interpretations of crystalline basement and sedimentary cover relationships which have arisen during the compilation of the map data for the South Australia region. The writer also takes the opportunity in this paper to revise and amplify tectonic aspects of his contribution to the first three chapters of the "Handbook of South Australia Geology" (Parkin, 1969) in the light of new information from geophysical and geological surveys and exploratory drilling.

The valuable stratigraphic drilling done by the South Australian Department of Mines in the last two years has meant important advances in basic geological knowledge, particularly of the poorly known subsurface geology of the central and western areas of the State.

In 1969, the Australian Mineral Development Laboratories (AMDEL) in collaboration with the Geological Survey of South Australia began major regional K/Ar radiometric dating projects on the geochronology of the Precambrian basement rocks of the Musgrave Block and Gawler Block. Some preliminary dates from these projects have recently clarified several uncertainties in the tectonic interpretation of both areas.

TECTONIC CONCEPTS

Tectonics (or geotectonics, when applied to structures on a regional scale), is defined by Dennis (1967) as . . . "the science of the structure of the earth's crust, and of the movements and forces which have produced it. (Derivation: Greek, *tekton*, a builder; *ge* earth.) . . .

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From its derivation, tectonics implies an analogy with architecture, and, in fact, tectonic maps have been described as portraying the architecture of the earth's crust by means of symbols.

Owing to the interpretative character of the science, tectonic terms have acquired numerous shades of meaning. An interesting example is the term *Platform*, which is of fundamental importance. It appears to the writer to have been used in a slightly different sense in North America to that which has been employed by Soviet geologists in the compilation of tectonic maps of Europe and Asia. Since the concepts involved appear to the author to apply closely to the Precambrian tectonics of South Australia, they will be discussed in some detail. King (1969), in his authoritative explanatory notes to the new tectonic map of North America, defines a platform as—(p. 86) “. . . *That part of a continent which is covered*^o by flat-lying or gently tilted strata, mainly sedimentary, which are underlain at varying depths by basement rocks that were consolidated during earlier deformations. . . .” *A part of the craton of the continent*^o. French “plateforme” . . . on p. 21 he adds in reference to basement “consolidated, not only by earlier deformation but in part by metamorphism and plutonism”. Note that *Craton* is defined (Dennis, 1967), as “a relatively stable segment of the earth's crust undergoing no more than epeirogenic deformation”. King's definition of platform has been accepted by Dennis (1967), as the English terminology definition of platform in the International Tectonic dictionary. King's term clearly refers to only part of a craton and is *restricted to areas which retain cover*^o—in fact the emphasis is on the platform deposits (i.e., cover), and the areas of platform deposits are separated according to their age, independently of the age of basement. This classification and portrayal of tectonic units serves to emphasize basin development.

The usage has been adapted in part by the Australian Tectonic map Committee for the proposed tectonic map of Australia although a broader concept of platform involving generalization of the cover rocks is employed.

The following description by A. A. Bogdanoff, a recognized world leader in tectonic mapping, also outlines a somewhat broader platform concept. . . . “The East European platform is a *typical Precambrian platform (craton)*. Its basement is formed of *Precambrian metamorphic series and ancient intrusive rocks which outcrop as the Baltic Shield and Ukrainian massif*.† Within the vast territory of the west of the platform, known as the Russian plate, the basement surface occurs at considerable depths 1 to 3 km and locally down to 10 km and is overlain by a thick cover of undislocated, non-metamorphic, predominantly sedimentary formations. The platform cover is composed of Riphean, Paleozoic, Mesozoic and Cenozoic series the sequence of which is most complete within deep depressions of the plate. The problem of the exact position of the platform is one of the cardinal and, in many respects, still unsolved problems of the tectonics of the East-European platform. The present outlines of the platform are marked by the position of marginal parts of fold belts framing the platform. *The age of the platform is determined by the time when its folded basement was consolidated*,^o . . .” (Bogdanoff, 1964). Bogdanoff in contrast to King (op cit) here places emphasis on the age of basement rather than of age of cover.

The above description has much in common with the tectonic pattern of the Precambrian basement in South Australia. The writer (Thomson, 1965), first applied the term Gawler Platform to the area which included the Gawler

^o Author's italics.

† Author's italics. It is assumed here that platform basement: shield and massif are part of the craton.

Cratonic Nucleus of Sprigg (Dickinson and Sprigg 1953, p. 429) and its extension in the subsurface. Subsequently the writer (in Parkin 1969, p. 25), has extended the term to include part of the continental shelf areas to the south and west. Although this usage of platform may incorporate basement areas of similar time range, it is too broad to agree with international nomenclature, therefore to avoid confusion with anticipated nomenclature of the forthcoming Australian map, it is proposed that the term *Gawler Craton*^o be adopted in lieu of *Gawler Platform*^o. Craton is used in the sense of Dennis (ibid). This usage has the advantage of applying a specific geological time interval (i.e. post-Carpentarian) to a structural feature which in part is basement to some areas of a more extensive "Central Australian Platform". The Gawler Craton includes Gawler Block, Yorke Peninsula basement and shelf areas, Mt. Woods and Wallabying Inliers, Stuart Shelf, southern margin of Officer Basin, portion of Eucla Basin, offshore areas in the Great Australian Bight and Eyre Peninsula and northern Kangaroo Island. Details of the geology of the Craton will be given later in this paper which is largely concerned with basement tectonics.

The term "shield", although strictly applying to individual extensive *out-cropping* areas of basement rock (Dennis, 1967), has not been used in a strict tectonic sense in the case of "the Australian Shield". This expression has loosely come to mean that part of the continent containing crystalline Precambrian crustal rocks. Note here that Doyle et al. (1968), discussing seismicity, considers it quite likely that Precambrian rocks extend under eastern Australia as part of the "granitic" layer detected by seismic methods.

Confusion in tectonic terminology and nomenclature also arises from changes with time of spatial relationships between parts of the crust. As an example, the Precambrian basement ages of the Gawler Craton correspond closely with those of the Precambrian Willyama Block to the east (Compston and Arriens, 1968). It is reasonable to assume that the two tectonic units once formed part of an older larger craton. The writer believes that the development of the Adelaide Geosyncline and of a subsequent Palaeozoic fold belt destroyed the cratonic character of the eastern region of the older craton which has since retained a mobile character distinguishing it from the Gawler Craton proper. An analogous problem is in the naming of sedimentary basins which belong to separate tectonic and depositional cycles but which are in part superimposed on each other. Wopfner (1969a) has employed a separate name for each basin associated with a specific cycle in the Phanerozoic basins of South Australia. Where information is available his system will be followed in this paper.

THE PRECAMBRIAN BASEMENT

(1) *Fold belt trends in Southern Australia*

Crystalline basement structures have played a fundamental role in the development and tectonic history of Phanerozoic sedimentary basins (Wopfner, 1969a) and localization of metallogenetic provinces in South Australia (Thomson, 1965). As a consequence, the fullest possible study of the basement is justified if long range assessment of future mineral resources is to be seriously attempted.

The setting of the South Australian region in the Australian Precambrian crystalline basement framework is illustrated by Fig. 1. This figure has been greatly simplified from the current draft of the 1:5,000,000 tectonic map of Australia in preparation by the Geological Society of Australia. Structural trends are emphasized, fault structures have been omitted for clarity. The nomenclature

^o Author's italics.

of Daniels and Horwitz (1969), has been adopted for the tectonic units in western Australia. Radiometric age limits have been adopted largely from Compston and Arriens (1968).

The basement trend lines represent the traces of fold-belts that have generally undergone more than one phase of metamorphism and deformation e.g., in the Willyama Block (Binns, 1964; Talbot, 1967; Vernon, 1969). The structural overprinting leads to patterns in rock layering that, although bewilderingly complex in detail, are believed by the writer to be tectonically meaningful even when considered on the grossly generalized scale of Fig. 1.

(2) *Northwest trending features*

The northwest trending Archaean fold belts of the Yilgarn Block have not to date been recognized as such in the internal fold structures of the basement in South Australia. The northwesterly trending outline of the Gawler Block however, reflects the significant major basement features within the continental shelf to the west described by Smith and Kamerling (1969). The first of these is the continuation to the northwest of the Cygnet Fault from Kangaroo Island. This structure forms the seaward boundary of shallow Precambrian basement. Parallel to this boundary and farther southwest in the Duntroon Basin a deeper structure is outlined by a chain of basement ridges. This chain is in alignment with the southwestern margin of the Gawler Craton. At the head of the Bight the same zone is marked by an intracratonic trough in the basement cover (Fig. 3). Further to the northwest within western Australia, a marked change in trend of the deep trough of the Officer Basin around the Musgrave Block is located in the same zone. Still further west, Archaean structures in Yilgarn Block basement appear to control fold trends in the Bangemall Basin sediments of probable Adelaidean age. The northeastern flank of the Gawler Craton is also the site of a swarm of shallow northwest trending positive aeromagnetic anomalies which may represent basic dykes (Webb and Woyzbun, 1967, see appendix)* such as occur in the Musgrave Block. The Adelaide Geosyncline and the alignment of the Willyama, Mount Painter and Denison Blocks are an expression of a bigger regional feature incorporating the MacDonald Shear Zone, Norwest Fault, Muloorinna gravity ridge, Lake Eyre and Lake Blanche Faults. To the southeast of the State the prolongation of the Padthaway Ridge marks a major northwesterly swing in trend of the northern margin of the deep Mesozoic-Tertiary Otway Basin which is very similar in structural style to the interpreted pattern of the Duntroon Basin and likewise may have a metamorphic Palaeozoic basement (Wopfner, in Parkin 1969, p. 161).

South of the Otway Basin, Precambrian rocks reappear on the same trend in King Island and Western Tasmania where they are probably affected by late Precambrian folding and plutonism (Compston and Arriens, 1968). Although most of the northwest trending structures described are evident as a result of Phanerozoic tectonism, it is interesting to speculate that they may reflect fundamental northwest trending structural features that were established in the crust in Archaean times. The writer has already proposed, from stratigraphic and structural evidence (Parkin, 1969, p. 28), that a continental Archaean crustal basement underlay South Australia in Lower Proterozoic time.

* For the purposes of the following discussion use has been made of a number of unpublished Reports. The full titles of these are given as an appendix to the References at the end of the paper. This is indicated in the text by inclusion of (see Appendix.) at each such notation.

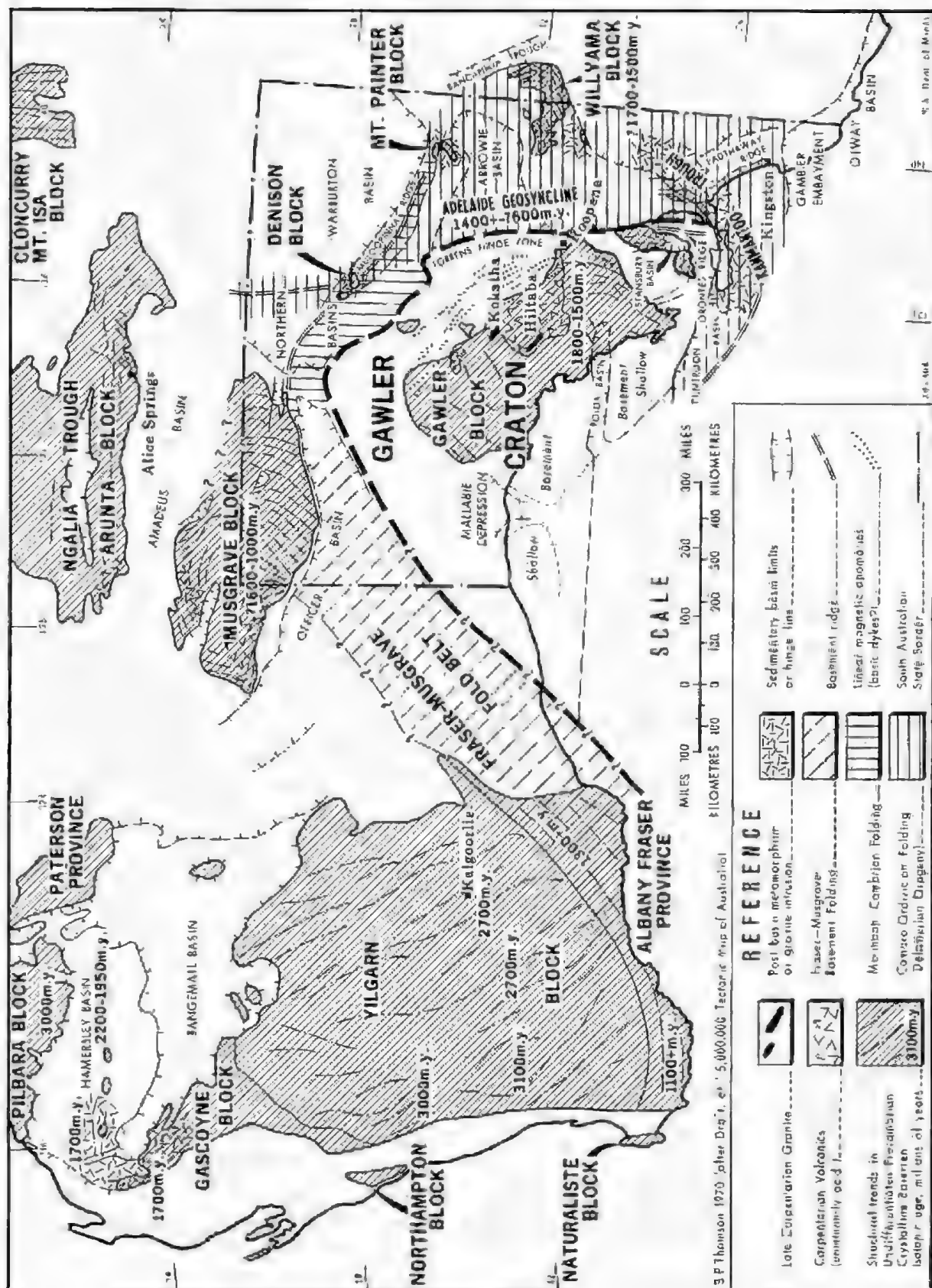


Fig. 1. Tectonic framework of Southern Australia.

(3) *Northeast trending features and the Gawler Craton Boundary Problem.*(1) **THE FRASER-MUSGRAVE FOLD BELT**

The Precambrian geology of the eastern part of the Albany-Fraser Province flanking the Archaean Yilgarn Block has been outlined by Wilson (1952, 1969), Morgan et al. (1968), and Doepl (1969). The latter believe the gneisses on the southeast coast to be of Archaean age, although this fold belt is at right angles to the known Archaean fold belts in the Yilgarn Block. Shallow crystalline basement continues, under the Eucla Basin (Peers and Trendall, 1968), Ludbrook in (Parkin, 1964, p. 195), and under the Great Australian Bight (Smith and Kameiling, 1969) and deepens to the northeast under the Officer Basin, reappearing at the surface in the southern part of the Musgrave Block which has a dominant northeast trend (Thomson, in Parkin (1969), p. 24, 34-45). The central and northern parts of the Block however have a complex pattern in which northeasterly trends are largely obscured by other cross-cutting structures. Within the Arunta Block to the north, in the Alice Springs region, northerly to northeast fold trends are preserved within strong east-west structures. These northerly trends are considered to be relics of folding which was associated with the Arunta Orogeny, prior to development of the Amadeus Basin (Wilson, 1953; Wilson et al., 1960; Wells, 1969). Further support for the interpretation that a major transcontinental structural feature exists, is provided by the striking alignment of the southern limits of outcrop of the Mt. Isa-Cloncurry and Georgetown Precambrian basement inliers in Queensland with the eastern limits of the Arunta and Musgrave Blocks and the Fraser Range area. The writer believes that in the Fraser-Musgrave Ranges region this alignment represents a complex Precambrian fold belt associated with the Musgravian orogenic cycle (Parkin, 1969, p. 43) believed to have been active between 1400 and about 1100 m.y. The foldbelt contains some older crystalline basement rock units that suggest that the Musgravian cycle has overprinted on an older Carpentarian basement.

In the Musgrave Block and the Albany-Fraser Range Province, granites with radiometric ages between 1100 and 1200 m.y. have been recorded (Turek and Stephenson, 1966; Compston and Arriens, 1968). Arriens and Lambert (1969) obtained a 1328 ± 12 m.y. isochron for the granulite facies rocks in the Fraser Range and a less distinct 1380 ± 120 m.y. isochron for the granulite facies rocks of the Musgrave Ranges. Adjacent gneisses in both areas gave possible ages from 1660 to 1900 m.y. in the Fraser Range area and 1400 to 1650 m.y., in the Musgrave Range.

Arriens and Lambert (op. cit) associate the granulite isochrons with periods of rapid uplift and favour a geosynclinal and volcanic origin for the granulite facies rocks. The writer on the other hand, considers that the granulites in part, at least, represent sediments that were deposited during the Lower Proterozoic and were probably first incorporated in a fold belt in the Carpentarian (1800-1600 m.y.) (Thomson, in Parkin, 1969, p. 43). According to Arriens and Lambert (Ibid. p. 385) such an interpretation, in order to explain the low $\text{Sr}87/\text{Sr}86$ initial ratios of the granulite rocks, would require selective expulsion of $\text{Sr}87$ during metamorphism. A further complicating factor that should be noted, is that both sampled areas of granulite rocks adjoin profound regional fault zones which must represent zones of immense, and possibly oscillating vertical movements during the Precambrian with consequent effects on possible "cooling dates" (Moorbath, 1967) of these rocks and opportunities for isotopic fractionation and diffusion. The isotopic evidence where stratigraphic evidence is not available, nevertheless is of great value in providing the only method for distinguishing crystalline rocks of the Fraser-Musgrave Fold belt from those of the Gawler

Craton. At present the minimum age of the Gawler Craton plutonic and metamorphic rocks is assumed to coincide with the 1400 m.y. Adelaidean-Carpentarian time boundary.

Webb (1970) (see appendix) has determined K/Ar radiometric ages of biotite and hornblende from granitic rocks in the Musgrave Block and Gawler Craton. These preliminary results show that Gawler Craton gneissic basement (i.e. ages in excess of 1400 m.y.) persists in the subsurface to at least as far north as latitude 28°S, whereas the granites in the eastern end of the Musgrave Block have been affected subsequent to emplacement, possibly at ca. 1100 m.y., by a metamorphic event at probably about 1000 m.y. This last event corresponds to the Winanayan Phase of the Musgravian Orogeny proposed by the writer (in Parkin, 1969, p. 44-45). The northwestern boundary of the Gawler Craton shown on Figure 1 was interpreted as coinciding in depth with the Cambro-Ordovician and Adelaidean hinge zone located by Wopfner (1969a, Fig. 1b) in the subsurface of the eastern Officer Basin. This boundary has been extrapolated to the southwest following approximately the 2 km aeromagnetic basement contour derived from an interpretation by Adastral Hunting et al. (1965) (see appendix) (see Fig. 5 this paper). Below the Eucla Basin in Western Australia the boundary is assumed to pass between Eyre No. 1 and Madura No. 1 bores where Ingram (1967) has recorded a thickening in Cretaceous cover. It is suspected by the writer that this feature may be controlled by a northeast trending basement structure. In the western area of the Great Australian Bight, the boundary would cross the continental shelf eastwards of the Archipelago of the Recherche where Morgan et al. (op. cit.) record that a granite, considered by them to be the equivalent of the 1100 m.y. Albany Granite (Turek and Stephenson, 1966), has intruded an older layered sequence. Following this intrusive event the sequence was folded into a broad anticlinorium.

(ii) THE GAWLER CRATON

(a) Granulites and structural relationships

Granulite-facies rocks may not be confined to the Fraser-Musgrave Fold belt in the subsurface, as recent mapping and petrographic examination of exploratory and stratigraphic bores to basement has established that a major zone of granulite-facies rocks, not recorded by Wilson (1969), extends apparently in a northeasterly direction across the northern end of the Gawler Block. The zone is also represented by granulites in the small inlier of Mt. Woods further east and, in the subsurface to the north, in Wallira No. 2 bore (Fig. 2).

The age of the granulite metamorphism in this area has not yet been dated, however, Webb (1970) (see appendix) using biotites from gneiss of apparently lower metamorphic grades, in Wallira No. 1 and Mt. Fumer No. 1 bores (Fig. 2) obtained K/Ar dates of 1460 m.y. and 1432 to 1439 m.y. respectively. Wallira No. 1 bore occurs near a granulite area and Mt. Fumer No. 1 bore is located apparently to the north of the zone. Since the biotites would be sensitive to post-granulite metamorphic events, the true granulite ages are interpreted as possibly considerably greater than the indicated biotite ages and coeval, with the metamorphism of the ca. 1800 m.y. Kimban phase of tectonism of Eyre Peninsula to the south. The possibility that the granulite-facies rocks of the Craton extend below cover to the northwest to adjoin the zone of granulite metamorphism of the Fraser-Musgrave Fold belt, raises again the question that some areas of regional granulite metamorphism in the Musgrave Block may be of considerably greater age than the 1380 m.y. age proposed by Arriens and Lambert (1969) in the Ernabella area. The northwestern and southeastern position of the Gawler

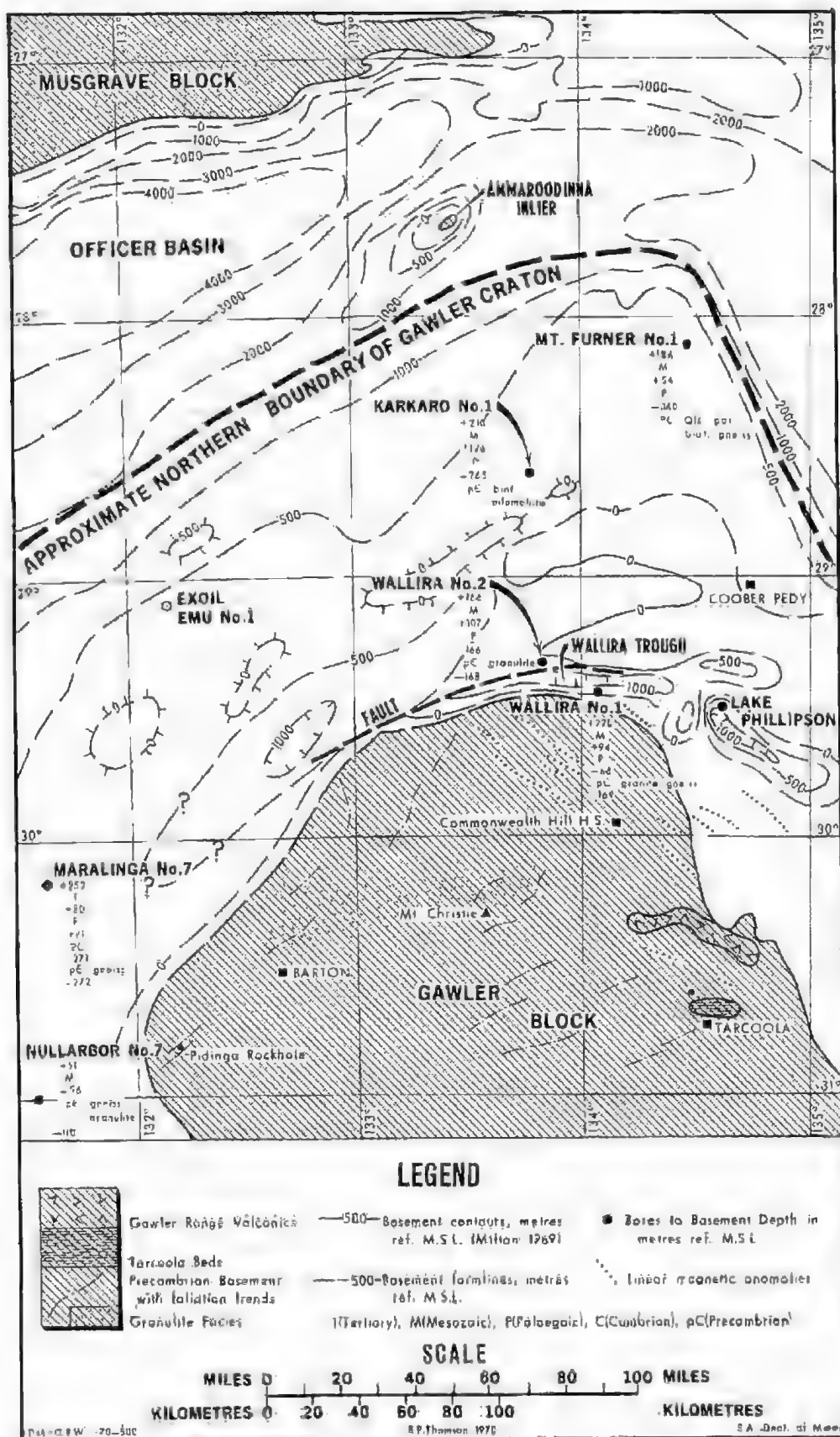


Fig. 2. Basement Structures; Northern Gawler Craton.

Block (the major outcropping part of the Gawler Craton) is made up of the Cleve Metamorphics, which the writer correlates with part of the Lower Proterozoic Mt. Bruce Supergroup (Daniels, 1966) of the Hamersley Basin in Western Australia. The Mt. Bruce Supergroup sediments are considered to have a time range of from 2200 to 1950 m.y. (Compston and Arriens, 1968).

The Cleve Metamorphics contain two major iron formations which provide important keys to regional structures. Whitten (1966) (see appendix) demonstrated, from mapping and study of aeromagnetics, that a northeasterly trending anticlinorium is present in the Wilgena-Mt. Christie area (Figs. 2 and 5) and that a major synclinorium occupies a large part of the southern Eyre Peninsula. The western limb of the synclinorium extends northwards along the west coast to Elliston and from there strikes northeasterly to Warramboo. The eastern limb follows the trend of the Lincoln and Cleve Uplands and then continues northwards through the Middleback Ranges.

Subsequent regional mapping (see Fig. 7, Parkin 1969) shows that north of Cleve the synclinorium trends to the northwest, it consequently has a syngnoidal outline in plan, indicating that it has undergone more than one period of deformation. The overall trend of the synclinorium however, remains northeasterly. The presumed anticlinorial area north of Elliston is poorly exposed and it is feasible that it may represent the metamorphosed equivalent of Archaean basement. No radiometric dates are available from the area. Whitten (*op. cit.*) interpreted the iron formations revealed by aeromagnetics and drilling in northern Yorke Peninsula as occupying an east-facing anticlinorial limb structure, striking north-northwest. A consequence of this interpretation is that the lower part of the Spencer Gulf area is largely occupied by a north-northeasterly trending anticlinorium. This is supported by the northwesterly strike of basement foliation in the Sir Joseph Banks group of islands and the west-northwesterly strike of gneiss in southern Yorke Peninsula. In Gulf St. Vincent, the east-facing anticlinorial limb is probably marked by the meridionally-trending deep Orontes basement block from the head of the Gulf to the foot of Fleurieu Peninsula from where basement anticlinorial inliers reveal northeasterly trending infra-basement structures through the Mt. Lofty Ranges. The character of the basement in the subsurface to the north has already been mentioned above (Fig. 2). The isolated outcrop of basement at Ammaroodina Hill (Krieg, 1970), south of the Musgrave Block, has been assigned to the Fraser-Musgrave Fold belt since it appears to have participated in Palaeozoic folding of nearby Adelaidean and Palaeozoic sediments. Seismic and gravity investigations and stratigraphic drilling show that the northern limit of the Gawler Block is marked by narrow basement troughs which are frequently fault bounded. Isolated outcrops of granite gneiss along the northwest flank of the Gawler Block have been recently mapped by helicopter and northeast trending foliations established. (A. F. Williams pers. comm.)

(b) The Mallabie Depression

Basement cores and cuttings from selected bores in the Eucla Basin are being re-examined and Fig. 3a and 3b was drawn after study of available data.

The buried structure, revealed by drilling and geophysics records important events in the history of the Gawler Craton. The section studied includes the Mallabie No. 1 bore which was drilled for Outhack Oil Co. (Scott, 1969) (see appendix), to explore the trough revealed by a Department of Mines seismic refraction survey (Kendall, 1965) (see appendix). The basement profile shown on the section has been adjusted to follow approximately the shape suggested by Kendall's high speed refraction contours. The seismic results were complex in the western part of the trough where a refractor with 18,500 ft/sec (5.6 km/sec) to

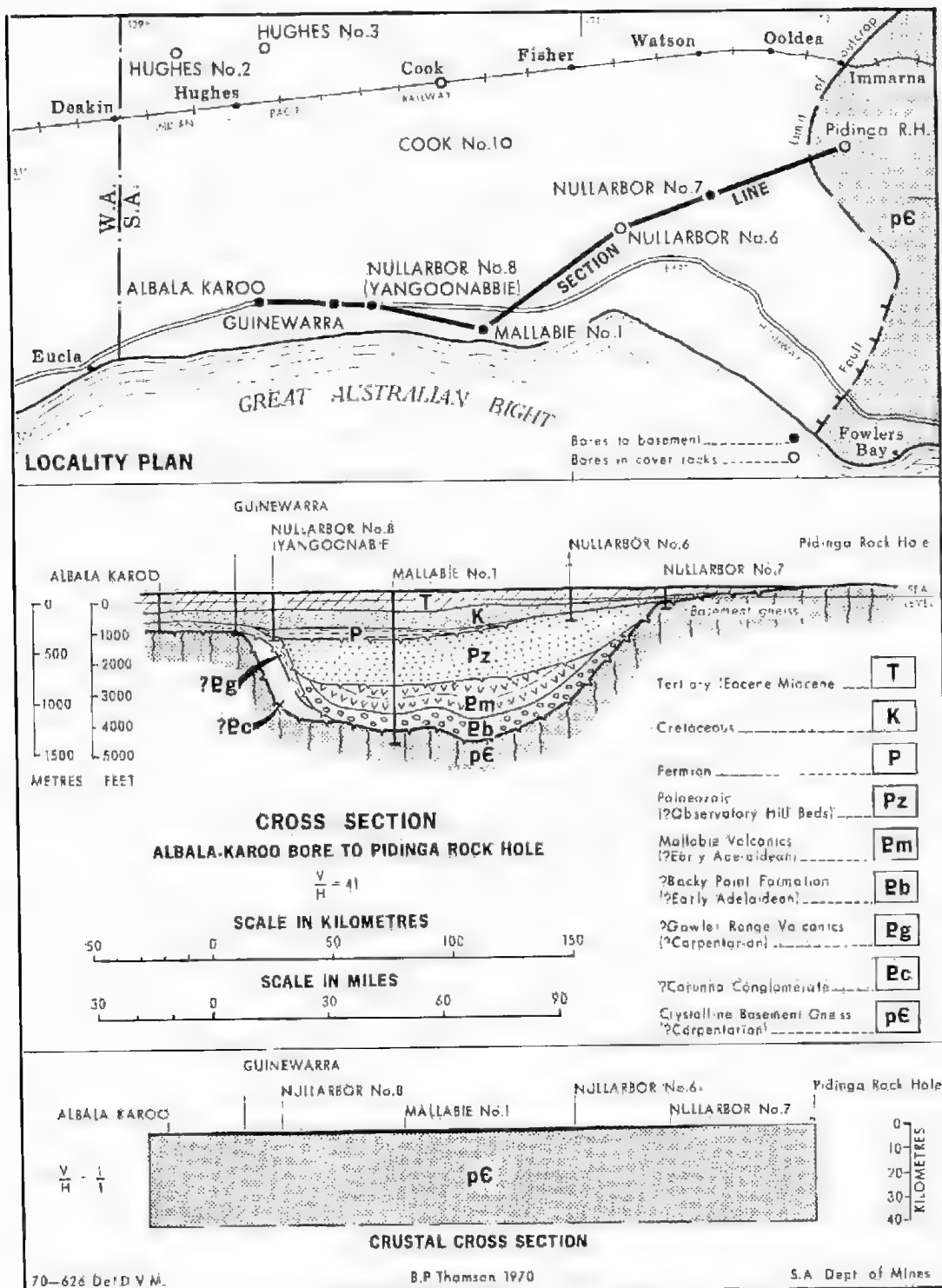


Fig. 3. Cross Section and location map of Mallabie Depression.

20,000 ft/sec (6.1 km/sec) velocities was assigned to the granite-porphyry basement, believed to have been intersected in the two western holes. A check of the cuttings from Albalá Karoo water bore, drilled in 1890, showed that from 1045 to 1073 feet depth, porphyry and rhyolite were present, below this depth to the bottom of the hole at 1084 feet, only one (inadequate) sample was available. The change from "hard blue rock" to "red granite" noted in the original 1890 log possibly represents a definite change to granite basement as assumed by Kendall.

Guinewarra Bore intersected amygdaloidal red and grey rhyolite and porphyry between 1066 feet and 1253 feet depth. From 1253 to the bottom at 1277 feet, unweathered granite gneiss is present*, thus confirming the original 1892 log of the hole which reported a change in this section from "hard red and blue rock" to "granite".

Seismic results indicate a rapid deepening of basement eastwards between Guinewarra and Nullarbor No. 8 bore. Kendall related the porphyry reported in the bottom of the No. 8 bore to a 16,500 ft/sec (5 km/sec) refractor, a deeper lower velocity refractor he interpreted as "Proterozoic sediments" underlying a "sill" of porphyry. Samples from No. 8 bore confirm that porphyry, including amygdaloidal rhyolite similar to the two western holes, is present from 1387 to 1470 feet. The remaining samples to the total depth of 1500 feet are unreliable, but probably represent volcanics.

The assignment of a lower velocity to the porphyry in the No. 8 bore than in the western holes may be correct if porphyry forms only a thin skin on high velocity granite basement in the western holes. The porphyry in all three holes is correlated by the writer with the Carpentarian Gawler Range Volcanics, on the Gawler Block to the east, noted also in Harris and Ludbrook (1966). Kendall's Proterozoic sediments, considered to be below Nullarbor No. 8, probably represent equivalents of the Corunna Conglomerate and Tarconla Beds, which occur as scattered infolded remnants in the Gawler Block to the east.

Mallabie No. 1 Bore did not intersect porphyry. The volcanics, by contrast, are entirely basaltic and are strikingly similar petrographically (Turner and Smale, 1969), (see appendix), to the Adelaidean Roopena Volcanics,† which cover part of the eastern flank of the Gawler Craton. Turner and Smale observed that the basalts contain a mineral assemblage consistent with a metamorphic grade between zeolite and greenschist facies which they suggest is the result of static burial, presumably under a much thicker cover than these rocks have at present. The volcanics are underlain by a shale-arkose sequence which the writer believes is the equivalent of the early Adelaidean Backy Point Formation which underlies and intertongues with the Roopena Volcanics in the Roopena and Cultana areas. The sediments rest with marked unconformity on steep dipping granitic biotite-hornblende gneiss with traces of altered basic rock. Radiometric dating of this rock is in progress. Similar basement with schist was intersected in Nullarbor No. 7 and occurs in outcrop at Lake Pidinga (King, 1951). The writer believes that these are probable equivalents of the Cleve Metamorphics associated with the Kimban phase of tectonism.

The above stratigraphic interpretation, if correct, demonstrates that the pattern of unconformities in this region records that only gentle epeirogenetic movements which have affected the crust since Carpentarian times. Doyle and Everingham (1964) and Doyle et al. (1968) using seismic data from nuclear explosions at Emu and Maralinga to the north and from natural seismicity,

* Miss P. Simpson (pers. comm.)

† The writer considers the volcanics at Mallabie and Roopena to be time equivalent. Scott (1959) assigns the Mallabie volcanics to the Cambro-Ordovician, presumably equating them with the Kufyong Volcanics of the Officer Basin. A. Webb (personal communication) has obtained basement K/Ar dates indicating volcanics may be less than 1100 m. yrs.

demonstrate that the continental crust in the Gawler Craton area has a remarkably uniform thickness of between 37 and 40 km. Using the 40 km crustal thickness which is probably accurate for this section, Fig. 3(b) clearly shows the mild character of the Mallabie depression. The areal shape of the depression is conjectural because of inadequate geophysical data. Kendall (1965) (see appendix) assumed that basement contours had northwesterly trends but subsequent aeromagnetic surveys to the south suggest that the trends are northeasterly. Current investigations to the northeast indicate that this is more probably correct and also, that the eastern margin of the depression is probably fault controlled.

The Pz unit is provisionally equated with the Observatory Hill Beds of Wopfner (1969b), of probable Middle to Late Cambrian age. The unit forms an extensive cover on the Craton to the north. For details of younger Phanerozoic cover see Scott (1969) (see appendix), Harris and Ludbrook (1966) and Ludbrook (in Parkin, 1969).

(c) Tectonic phases

The Gawler Block, the main outcrop area of the Craton, although including much terrain to the west that is unmapped because of extensive Quaternary cover, nevertheless provides some critical Precambrian stratigraphic relationships in South Australia which have been preserved because of the absence of Palaeozoic deformation e.g., Thomson in Parkin (1969, pp. 25-32) and Thomson (1966). The pioneer regional geochronological study by Compston et al. (1966) established a number of key reference dates which have been used by the writer in grouping phases of tectonic activity in the development of the Gawler Craton (Fig. 8). These phases are the Kimban (oldest), Charlestonian and Wartakan (youngest). Each phase is preceded by sedimentation and terminates with generally acid igneous activity which is followed by an erosional interval. Acid volcanism is important in the second and third phases. The first two phases would probably be equivalent to separate Phanerozoic orogenies.

An account of the regional structures outlined by the Kimban phase is given above, but the tectonic history of these features, particularly the limits and duration of the events, is speculative. The metamorphism has been dated at 1780 m.y. by Compston and Arriens (1968) mainly from samples of granulite from southern and eastern Eyre Peninsula. This date may reflect the time of uplift of selected parts of the block in this sector and consequently does not necessarily date the age of the earlier folding of the Cleve Metamorphics. The youngest unit of the Mt. Bruce Supergroup in Western Australia is the Wyloo Group (Daniels, 1966); it has some close lithologic similarities with the succession represented by the Cleve Metamorphics. According to Compston and Arriens (1968) the Wyloo Group has a minimum age of 1950 m.y. This age may be the maximum possible age of the Kimban phase. The Glenloth Granite, actually a granitic quartz-feldspar-biotite-gneiss, has been dated imprecisely at 1930 ± 200 m.y. (Compston et al., 1966). The Hiltaba Granite previously dated by Compston et al. (*ibid*) at 1,730 m.y. now appears from field evidence and K/Ar dating by Webb (1970) (see appendix) to have an apparent age of 1477 m.y. and belong to the Wartakan phase.

The termination of the Kimban phase is uncertain; it may be represented by deformed granite, intruding Cleve Metamorphics west of Cowell, and by the Tickera granite near Wallaroo which, although intrusive, appears in places to have gradational relationships with the gneisses of the Cleve Metamorphics equivalents. The M1 metamorphism of Binns (1964) and Vernon (1969) in the Barrier Ranges region of the Willyama Block has been dated at 1650-1700 m.y.

in the vicinity of Broken Hill by Pidgeon (1967) and Shaw (1968). A complex history is suggested since Binns, (1964, pp. 311-312), presents evidence that the Alma Augen Gneiss represents an igneous rock (?granite) that has undergone the M1 metamorphism. The gneiss itself has been dated at 1700 m.y., consequently the parent granite must be of greater age, possibly coeval with the Kimban phase. Support for the concept that the Cleve Metamorphics are the metamorphosed equivalents of the Mt. Bruce Supergroup is given also by the fact that on the southern flank of the Hamersley Basin the Supergroup is itself folded and intruded by the Boolaloo Granite which is dated at about 1700 m.y. (Compston and Arriens, 1968). This intrusive event probably records the close of the *Ophthalmian Folding* of Daniels (1966) which may approximate to the Kimban Phase.

Erosion and sedimentation with contemporaneous and predominantly acid volcanism of the Moonabie Formation and Moonabie Porphyry ushered in the *Charlestonian Phase* of folding, metamorphism and granite intrusion. The phase is represented typically by the coarse-grained Charleston Granite which has a well established isotopic age of 1590 m.y. (Compston et al., 1966). The phase may have ended with the intrusion of gabbroic rocks. Similar granites with approximately similar ages are the Burkitt Granite, granite near Wilgena and probably a coarse granite at Cooladdin Rock Hole north of Tarcoola. In northern Eyre Peninsula, these and other petrographically similar granites tend to be aligned in a northwesterly direction. The granites were intruded as discrete plutons up to 10 miles across. A similar rock in the Olary area of the Willyama Block is the Binberrie Adamellite, dated at 1580 m.y. (Compston et al. 1966).

At present the Moonabie Formation is known only on the eastern side of the Gawler Block. Possible equivalents elsewhere are the Freeling Heights Quartzite in the Mount Painter Block to the northeast and unnamed quartzites in the Peake Metamorphics in the Denison Block to the north.

After the *Charlestonian Phase* of folding, erosion of the Gawler Block again followed and the Corunna Conglomerate and the equivalent Tarcoola Beds, which include sandstone, shale and dolomite, were deposited in local intra-cratonic basins and were probably accompanied by acid volcanism. The *Wartakan Phase* commenced with the folding of these sediments and was then followed by a period of intense volcanism, predominantly rhyolitic in character (i.e., the Gawler Range Volcanics). Numerous rhyolitic breccia pipes penetrated the older rocks to the south and, according to Turner (1970) (see appendix), the main mass of the Gawler Range volcanics was extruded rapidly at about 1535 m.y. (Compston et al., 1966) in a large cauldron subsidence area in the eastern part of the Block. The subsidence area was bounded to the south by the east-west Uno Fault against which the sheet of tuffs, welded tuffs and lavas were upturned. Subsidence was most active after major explosive eruptions. The main sheet spread over a known area of about 12,000 square miles and it is clear that it was originally much more extensive, possibly covering most of the area of the Block and to the west of the Mallabie depression.

The *Wartakan Phase* concluded with the intrusion of dykes of rhyolite near Lion Knob and Tarcoola and the Mnonta Porphyry on Yorke Peninsula at 1470-1480 m.y. (Compston et al., 1966). The sheet of gently dipping Gawler Range Volcanics was intruded by small plutons of leucocratic micrographic potassic granite in two known localities. The first at Kokatha (Fig. 4), near Kingoonya intruded the base of the Gawler Range Volcanics which, here, are interlayered with basalts and microgabbros. The second locality is at Hiltaba further south, near the western margin of the main Gawler Range volcanic sheet. A pluton of Hiltaba Granite, petrographically similar to the granite at Kokatha, has gently

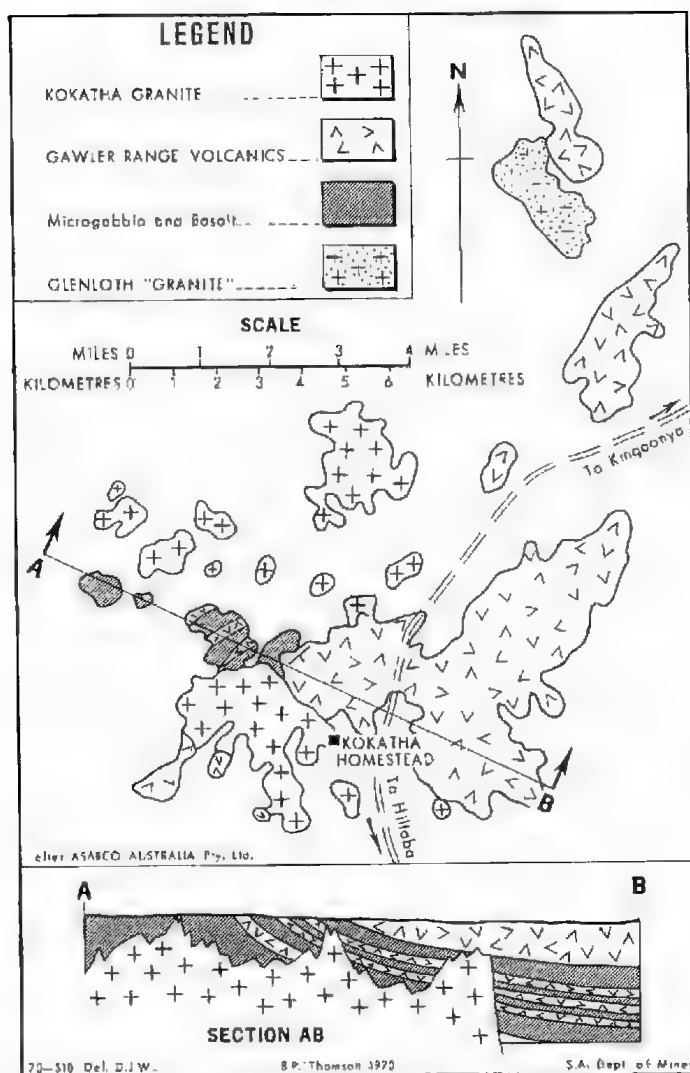


Fig. 4. Geological map of Kokatha Area.

intruded and slightly domed the generally flat-lying rhyolite sheet. From the granite, Webb (1970) (see appendix) obtained a K/Ar biotite age of 1477 m.y. which the writer believes may be near the age of emplacement and thus represents the final igneous event that marked the end of the Wartakan phase and consolidation of the Gawler Craton. Minor dolerite dykes in the Craton may be post-Wartakan in age. They are possibly equivalents of Roopena Volcanics.

(iii) THE EASTERN INLIERS

The small inliers of the Mount Lofty Ranges and Anabarna area occur on the "Mount Lofty-Olary arc" of Campana (1955). This connects the Willyama Block by a lower Palaeozoic fold belt to the southern margin of the Gawler Craton. Campana considered the arc to be an expression of "framed tectonics" resulting from the reaction of a plastic basement in the fold belt to compressional

movements between the Gawler Craton and a buried craton below the Murray Basin. However, this writer believes that the arc is an expression of "vertical tectonics" and that the underlying basement itself is the main contributor to the mechanical deformation that formed the arc.

Although much deformed by Lower Palaeozoic folding, the "grain" of basement layering is dominantly that induced by pre-Adelaidean northeast trending fold belts. This is particularly evident in the Willyama Block (Fig. 8, in Parkin, 1969) and regional maps in King and Thomson (1953) and Thomson (1969). The pattern of folding of the cover constantly seeks to adjust itself to the more complex structural pattern of the basement. For example, in the Northern Barrier Ranges the anticlinorium trends northeasterly although it is formed by individual northerly trending folds in the cover. This trend of the anticlinorium reflects the actual trends of basement layering below the Adelaidean northeast dipping unconformity surface.

In the Mount Painter Block the southern inlier has a dominant northeasterly trend. This probably continues to the northeast in the shallow crystalline basement block which forms the northeastern flank of the Cambro-Devonian Warburton Basin of Wopfner (1969a). The basement inliers in the Denison Block have internal layering striking northeast. This controls the alignment of a chain of basement inliers extending for 30 miles from the vicinity of Nilpinna Homestead to Lagoon Hill on the western margin of the Great Artesian Basin. This lineament (see Fig. 10, Parkin, 1969) is also the locus of intrusion of plugs of "granite", now identified as quartz monzonite and syenite, which intrude the Adelaidean (Torrensian) sediments.

The geochronology of these intrusions is being investigated. At present it is uncertain whether they are of Lower Palaeozoic or late Adelaidean age as suggested by Wopfner (1969a, p. 15).

(4) North trending structures

(i) THE ADELAIDE GEOSYNCLINE (SPRIGG, 1952)

(a) Regional Extent

This major Precambrian feature is clearly recognizable as extending between the Willouran Ranges, near Marree in the north, and the Mount Lofty Ranges to the south. To the west it is bounded by the Gawler Craton.

The boundary between the Gawler Craton and the Adelaide Geosyncline is placed tentatively on a complex fault structure, the *Torrens Hinge Zone* (Fig. 5), which is thought to extend from the northern end of Lake Torrens and southward through the head of Spencer and St. Vincent Gulfs. This boundary is truncated in the south by the Cygnet Fault (between Kangaroo Island and Fleurieu Peninsula) and to the north by the Norwest Fault in the concealed area between the Willouran and the Peake-Denison Ranges.

It may be argued from the evidence of intensity of folding, or basement depth, that the boundary should be selected east or west of this line. The writer believes that this choice of boundary separates an area of cover to the east which has a much more complete stratigraphic record than that to the west. The Torrens Hinge Zone incorporates the area of the Tertiary graben belt extending from Lake Torrens to the St. Vincent Gulf and westwards to the vicinity of Mount Gunson. Because of its metallogenetic associations, this zone is being explored by the Department of Mines and private companies (e.g., Webb and Woyzbun, 1967) (see appendix). The eastern flank of the zone is the most active seismic area in the continent (Doyle, Everingham and Sutton, 1968, p. 302).

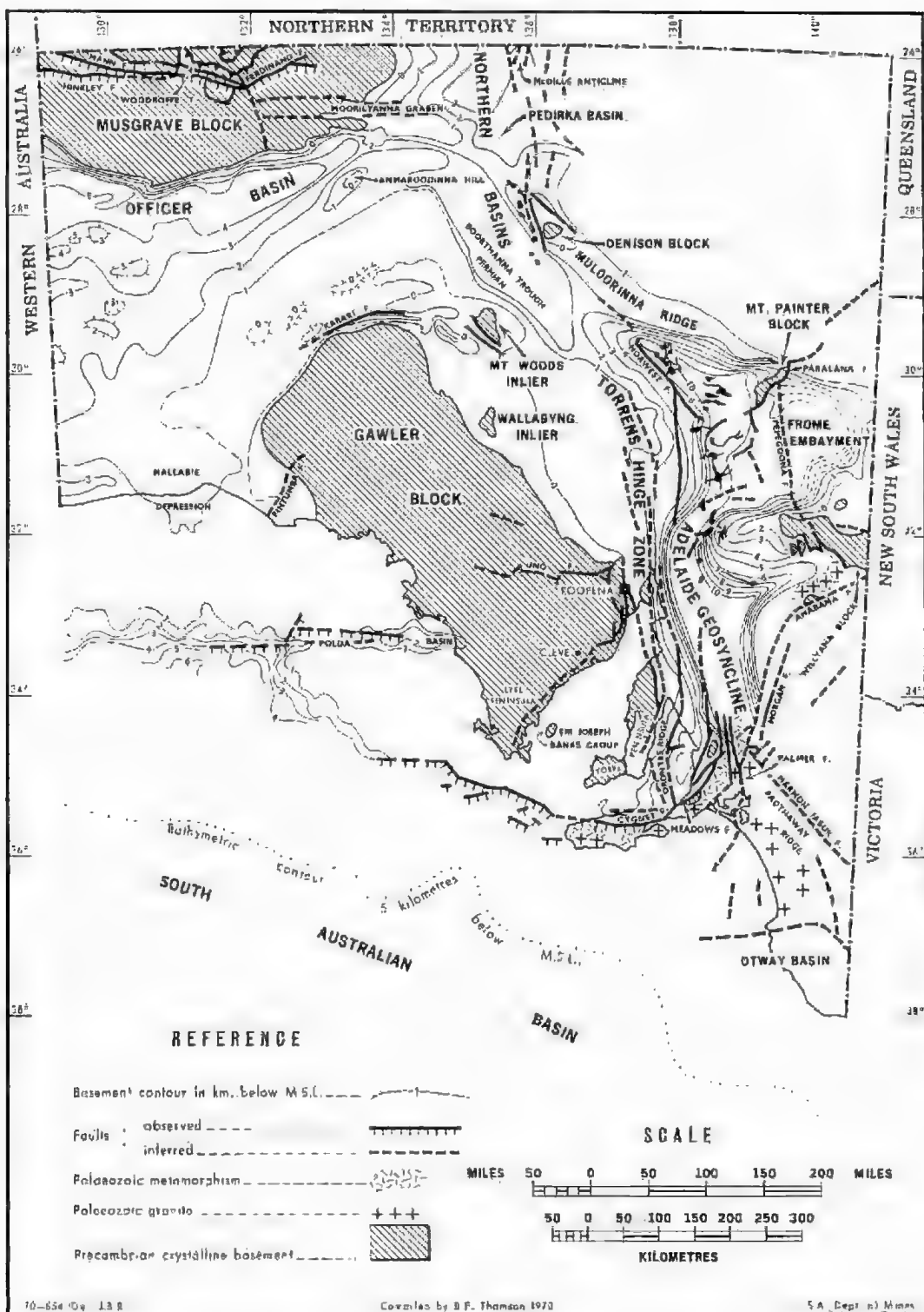


Fig. 5. Precambrian basement contours, form lines and other structural features in South Australia.

To the southeast the Geosyncline appears to be flanked by a Cambro-Ordovician fold belt extending to the north east. The Willyama Block and the shallow crystalline basement east of the Palaeozoic Arrowie Basin (Wopfner, 1969a) forms the eastern margin. The northern margin is formed by the Muloorinna Ridge extending between the Mount Painter and Denison Blocks. To facilitate the study of the Geosyncline and related features in South Australia the writer has prepared a basement contour map (Fig. 5) from all data available to him (Appendix 1). The map is largely a compilation of aeromagnetic basement interpretations by the Bureau of Mineral Resources and petroleum exploration companies and, where possible, it incorporates seismic and stratigraphic drilling data (e.g., Milton, 1970) (see appendix). On the whole the map probably should be referred to as a basement form-line map. In poorly known areas it is likely that basement depths are probably more shallow than shown. The basement depths in the central zone of the geosyncline are very conjectural as the effect of Lower Palaeozoic metamorphism has dominated the aeromagnetic record. The maximum basement depths in excess of 10 km have been estimated from stratigraphic thicknesses. In places it has not been possible to allow for the effect of decollement which has occurred. South of the Willyama Block the presence of the Palaeozoic Anabama granite and marked regional metamorphism has converted the geosynclinal sediments to new crystalline basement. A north-south basement fault probably extends from the Olary area (below the Frome Embayment) to the Mount Painter Block and, together with associated Palaeozoic granites (Coats and Blissett, 1970), is in alignment with the western limit of the Anabama Granite. South of the Anabama Granite area, north trending basement faults appear to influence the aeromagnetic basement contours.

(b) Duration of the Adelaide Geosyncline

The writer has maintained (Thomson, 1966) that the geosyncline contains sediments extending back to about 1400 m.y. The consequent concept of an Adelaidean System is fundamental to the time-stratigraphic subdivision of the Australian Precambrian which was proposed by Dunn et al. (1966). Subsequent investigations, such as the stratigraphic drilling of the Mallabie depression described above and in the Roonena area (Fig. 6) on the eastern flank of the Gawler Craton, support this concept. A strong argument that the conventional role of biostratigraphy may yet be employed for world-wide correlation in the Precambrian is advanced by Glaessner et al. (1969) who demonstrate that the evidence of stromatolites in the Geosyncline supports a middle Riphean age (1350 ± 50 to 950 ± 50 m.y.) for the Callanna Beds either alone, or including the overlying Burra Group. For a recent summary of the stratigraphic record of the Geosyncline the reader is referred to Parkin (1969, Chapter 2).

The effect of the Musgravian orogenic event on the Adelaidean sequence in the Geosyncline has yet to be elucidated. The writer has assumed in (Parkin, 1969, p. 52) that a break in sequence between the Upper and Lower Callanna Beds may have resulted from this event. The duration of this assumed regional hiatus may be resolved by close study of the stratigraphy and geochronology of the Duff Creek Beds along the north-east side of the Gawler Craton in the vicinity of the Denison Block and further south in the Willouran Ranges area.

(c) Palaeogeography

The earliest known event was probably the development of a sheet of basin sediments (mainly continental), associated with basic volcanics, extending from the Mallabie Depression eastwards to the north of the Willyama Block. The sequence probably passed into a marine facies to the north for example, marginal

to the Painter Block. The source area to the south was the basement established in the Carpentarian-Wartakan tectonism. The basin was probably terminated to the west by the Fraser-Musgrave fold belt. The orientation of the original basin is obscure. In later Willouran and in Torrensian time the Upper Callanna Beds and Hurra Group were deposited in a deep trough bounded to the west by the Torrens Hinge Zone, and show that the Adelaide Geosyncline was a downwarped structure in older cratonic basement. The Cawler Craton area to the west became a major source area for the sediments. Subsequent Sturtian and Marinoan troughs in the Geosyncline appear to have had their thickest developments east of this Late Willouran-Torrensian trough (Thomson, in Parkin, 1969). The palaeogeographic relationship of the Torrowangee Group (Rose and Brunker, 1969), on the eastern flank of the Willyama Block, with the Adelaide Geosyncline has not yet been resolved. The Torrowangee sequences show obvious close lithologic correlation with the Adelaidean of South Australia (Thomson, 1969). The Group probably occupied a separate eastern basin that had intermittent connection with the Geosyncline.

(ii) NORTHERN BASINS

Basement form-lines and scanty bore data indicate that remnants of Adelaidean cover form the floor of the Boorthanna Trough of the mid-Palaeozoic Arkarunga Basin (Wopfner, 1969a) and extend northwards below the floor of the Palaeozoic Pedirka Basin (Wopfner, *op. cit.*). A saddle structure connecting the Musgrave Block and the Denison Block appears to separate the basins. The Muloorinna Ridge forms the eastern flank of the basin chain and apparently connects with the McDills Anticline (Stewart, 1967) in the Northern Territory. The trace of the basin chain further north is obscure; it may die out within the saddle-shaped depression shown in the "McDills Gravity Platform" (Stewart, *op. cit.*, Fig. 2). This platform probably represents Musgrave Block basement. It is very likely, considering the stromatolite evidence of Glaessner *et al.* (1969), that the Adelaidean (?Torrensian) sediments which formed the floor of the Officer Basin and Amadeus Basin were deposited after the ?Willouran Duff Creek Beds. The palaeogeography of the areas of Willouran sedimentation remains to be resolved.

(iii) MAJOR GEOTECTONIC STRUCTURES

The Torrens Hinge Zone forms the western margin of a network of continental fractures trending west of north. The network covers a wide belt to the northeast and incorporates the Tiboooburra Ridge of Rose and Brunker (1969), and extends northwards to the Arnhem Land and Carpentaria areas of northern Australia where it has apparently affected Carpentarian sedimentation. Most of the major known Precambrian base metal deposits (e.g., Mount Isa and Broken Hill) are incorporated in this belt which is consequently of profound metallogenic significance. The southern prolongation is highly speculative, but, gravity, aeromagnetic features and the continental shelf north of the Gambier sub-basin of the Otway Basin suggest that the network has been active since the Cambrian-Ordovician (Delamerian) Orogeny. It is likely that the apparent displacement of the mid-ocean ridge between Australia and Antarctica which was interpreted by Heirtzler *et al.* (1968) from rather sparse magnetic data, is related to the same network of faults.

(5) *Transverse Trending Structures*

(i) GENERAL.

Numerous important features trending east-west or west-northwest truncate earlier established patterns of folding. Some of these features are graben or half

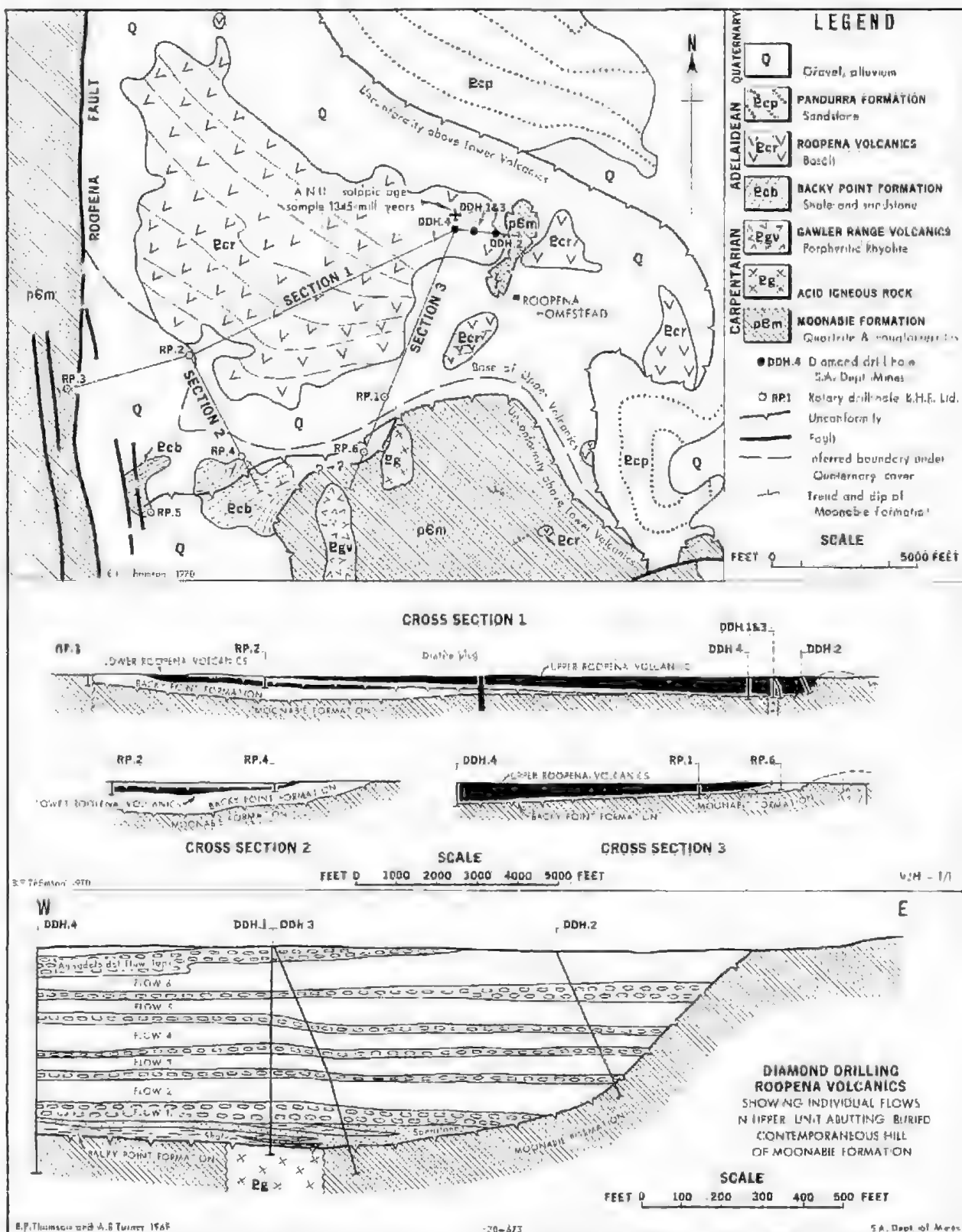


Fig. 6. Geological map and cross sections Roopena area.

graben structures apparently developed during a period of stress relief toward the end of, or long after, a major orogenic event. An example is the post-Tasman Geosyncline Otway Basin. The Cygnet Fault is a revived east-west structure in the Kangaroo Island area and forms the southern margin of the Tertiary St. Vincent Basin. In this area it coincides with the arcuate Cambrian Kanmantou Trough which developed around the southern and southwestern margin of the Gawler Craton. The Polda Basin (Wopfner, 1969a), incorporating the Elliston Trough of Smith and Kamerling (1969), probably acted as a graben in the Gawler Craton during the Mesozoic. The occurrence of the Blue Range Conglomerate of possible Palaeozoic Age on the eastern prolongation of this feature, near Cleve on Eyre Peninsula, suggests that the structure has a long history. The Uno Fault, further north on Eyre Peninsula, formed an important structure controlling the development of the Carpentarian Gawler Range Volcanics (Turner, 1970) (see appendix).

East-west alignment of diapiric structures and faults in the Adelaide Geosyncline flank a promontory of the Willyama Block basement extending west from the Olary Region. Sub-parallel to this feature is the extension into South Australia of the Thackaringa-Pinnacles Fault. This fault is a major Carpentarian and Lower Palaeozoic structure in the Broken Hill area (King and Thomson, 1953 and Binns, 1965). A final example is an important east-west structure separating the Mount Painter Block into two parts (Couts and Blissett, 1970) and affecting the eastern margin of the Adelaide Geosyncline.

The Musgrave Block (Fig. 7)

This is the most striking transverse Precambrian structural feature in South Australia. For a description of the geology of the area see Parkin (1969, pp. 39-45) and selected references accompanying this paper. Interpretation of the stratigraphy of the basement and cover rocks and the significance of radiometric dating is still controversial, so that adequate tectonic synthesis cannot yet be made. The Ernabella and Everardian tectonic phases proposed by the writer in Parkin (op. cit.) in excess of 1300 m.y., are somewhat obscure. Daniels (1969) (see appendix), Major (1970) and Krieg (1970) have established important stratigraphic relationships between metamorphic basement and Adelaidean cover in the Officer Basin region. The writer suspects that the 1046 m.y. date of Compston and Nesbitt (1967) for the Tollu Volcanics, on which much of the interpretation of the Precambrian stratigraphy of the Musgrave Block has previously been based, has been up-dated by the Winanyan orogenic phase, and possibly by intrusion of granite of the Kulgeran Phase (1100-1200 m.y.). The volcanics which form part of the Bentley Supergroup (Daniels, 1969) (see appendix), a sediment-volcanic assemblage, are tentatively correlated by the writer with the Gawler Range Volcanics and Corunna Conglomerate of South Australia of Carpentarian age. The volcanic assemblage rests unconformably on older metamorphic basement at MacDougall Bluff in Western Australia. The Pindvin Sandstone, which the oldest Adelaidean transgressive unit in the Birksgate Ranges area (Major, 1970), is believed by the writer to be the equivalent of the Townsend Quartzite in Western Australia (Daniels, 1969) (see appendix) and, in turn, of the Heavitree Quartzite in the Northern Territory (Wells, 1969). The Heavitree Quartzite is the earliest unit of the Adelaidean cover in the Amadeus Basin. It is of Torrensian age (Glaesner et al., 1969) and probably less than 950 \pm m.y., and is therefore likely to have escaped the deformation of the Winanyan Phase of the Musgravian Orogenic Cycle.

The Heavitree Quartzite in the western part of the Arunta Block rests unconformably on an assemblage of volcanic, sedimentary and metamorphic

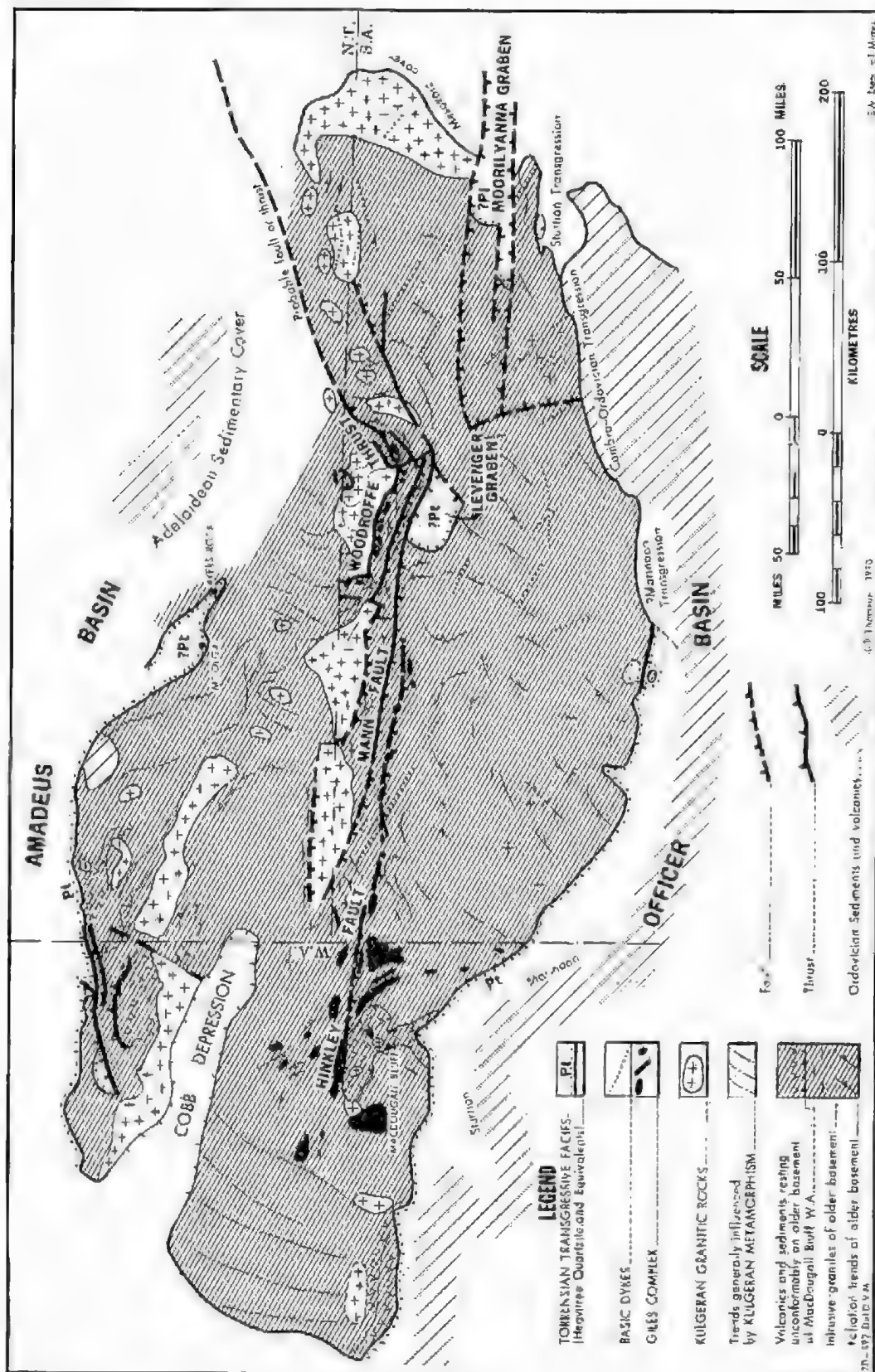


Fig. 7. Generalized Geological map of Musgrave Block.

rocks (Wells, 1968; Ranford, 1968). The writer believes that this is the same assemblage that occurs south of the Amadeus Basin between the Petermann Ranges and the Warburton Ranges and, except for the Townsend Quartzite equivalent, represents the Bentley Supergroup of Daniels (1969) (see appendix). The writer also believes that farther to the east, the possible metamorphic equivalents of the Bentley Supergroup are the Olla Gneiss and the (?) infolded Dean Quartzite of Forman (1966). The metamorphic equivalents in South Australia are probably the schists and gneisses north of the Woodroffe Thrust which are associated with granulites of the Kulgeran phase and the Winanyan overthrusting from the south by gneisses and granulites of the older Musgrave-Mann Metamorphics. This interpretation explains the contradictory gravity and aeromagnetic patterns in the Musgrave Block and southern Amadeus Basin (Stewart, 1967).

The identification of the Heavitree Quartzite equivalent in the southern Amadeus Basin remains a major problem. It is probable that it is represented in relatively shallow basins on the metamorphic basement just described. The west-northwest trending Ayers Rock-Mount Olga depression, the east-west Moorilyana Graben and its relic extension to the westnorthwest (south of the Mann Fault) and the Cobb Depression near Giles in Western Australia are thought by the writer to have developed at the close of the Winanyan Phase and to be occupied in South Australia, at least, by Adelaidean sediments probably of Torrensian age.

MARINOAN AND LOWER PALAEOZOIC TECTONISM

(1) *General*

Sedimentation in the Adelaide Geosyncline appears to have been terminated in the Middle Cambrian by the earliest tectonism of the Delamerian Orogeny (Thomson, in Parkin, 1969). By early Ordovician the Orogeny had incorporated the Geosyncline, Willyama Block and Kanmantoo Trough into a fold belt with important metallogenic associations. Prior to the Delamerian an earlier orogenic event affected the eastern margin of the Gawler Craton, Officer Basin and Denison Block regions. It was suggested by Wopfner (1969a) that the event was late Marinoan in age and was associated with granites intruding Adelaidean sediments in the Denison Block region. This interpretation is finding support from preliminary K/Ar ages for the granite obtained by Webb (1970) (see appendix) which indicate an early Cambrian age. Sedimentation appears to have resumed in the Officer Basin during early Ordovician while the Delamerian Orogeny was in progress in the Adelaide Geosyncline and further south and east.

(2) *Tectonism and Basin Developments*

East of the Musgrave Block the known record of Proterozoic (late Marinoan) sedimentation in the northern basins is sparse (e.g., Mount Crispe No. 1 well). It is probable that folding had already commenced in early Cambrian time in the zone connecting the Denison Block with the southeastern margin of the Musgrave Block and, in the floor of the Officer Basin where Cambro-Ordovician sediments were later deposited. This event is here named the *Indulkanan Folding*. A hiatus in the late Marinoan sedimentary cover of the eastern flank of the Gawler Craton suggests that in this region there was a Marinoan-Lower Cambrian epeirogenic movement which was probably synchronous with the mild *Duttonian Folding* in the southern part of the Geosyncline. By the close of the Marinoan, or earliest Cambrian, widespread regression had probably occurred over much of the Geosyncline. By contrast, this was followed in the Lower Cambrian by a widespread transgression associated with subsidence of the Geo-

syncline and marginal areas of the Craton. Wopfner (1969a) has demonstrated that positive movements of the Willyama Block took place at this time. According to Wopfner, near the end of the Lower Cambrian the *Circum-Denison Arc* formed a locus of areas of negative movements with compensating positive movements of the Gawler Craton and Willyama Blocks. Subsidence of the Arrowie and Stansbury Basins also occurred at this time. The most intense movements took place in the *Kanmantoo Trough* (Thomson, in Parkin, 1969), in an arc which roughly formed a mirror image of the *Circum-Denison Arc*. The Trough truncated the southwestern flank of the Gawler Craton and extended north-easterly to the Willyama Block. This eastern sector of the Trough obliquely truncates the Adelaide Geosyncline.

The central part of the Trough, adjacent to the southern extremity of the Craton was the site of major differential vertical movements on basement fault blocks. These vertical movements have been named the *Cassinian Uplift* (to the north) and the *Waitpingan Subsidence* in the floor of the Trough (Thomson, in Parkin 1969, pp. 99-101). The resultant erosional and depositional rates must have been extremely rapid as about 50,000 feet of poorly sorted elastics were deposited in the Trough before the end of the Lower Cambrian. Sedimentation in the Trough probably continued into the Middle Cambrian. These later sediments were removed by subsequent erosion. Positive movements connected the area of Cassinian Uplift with the Willyama Block. In the north, sedimentation in the *Circum-Denison Arc* commenced with a new transgression (Wopfner, 1969a) in the Ordovician and sedimentation probably continued until almost the Upper Ordovician when it was terminated by folding.

(3) *Development of the Southern and Northern Foldbelts*

After Middle Cambrian there was a hiatus in the sedimentary record in the Adelaide Geosyncline due to folding. The subsequent metamorphism of the fold belt was complex. In the Mount Lottly Range area of the fold belt Offler and Fleming (1968), have detected three phases of folding. Extensive faulting took place, pene-contemporaneously with plutonism and metamorphism. The region of the southern arc was converted into a crystalline basement massif by the early Ordovician, as indicated by isotopic ages of granites from Victor Harbour, Palmer and Anabama. Webb (1970) (see appendix) has recently established a similar age for granite from Kingston, thus demonstrating that the plutonism was widespread. The Willyama Block was folded and sheared during the Delamerian Orogeny and some pegmatite and minor granite intrusion probably occurred there at this time. The Block appears to have acted as a "hinge" area between the northern and southern fold belt arcs. The history of the northern fold belt arc is, at present, poorly known. It is likely that the basement along the Muloorinna Ridge was folded and intruded by late Precambrian or early Cambrian granite and later was upthrust to the south and southwest along an arcuate system of steep reverse faults. Northwest of the Mount Painter Block it is possible that this feature truncated a former northerly extension of the Adelaide Geosyncline. The geochronology of the apparently post-Adelaidean granites in the Mount Painter Block has yet to be adequately investigated. Current K/Ar evidence suggests that the Delamerian folding may not have affected the Musgrave Block or Offler Basin area. The fold belt probably extended north of the Denison Block to connect with the McDills Anticline (Stewart, 1968). The crystalline basement floor of the Geosyncline was apparently activated both mechanically and thermally at this time and numerous small base-metal ore bodies were emplaced in the Adelaidean and Cambrian rocks of the Geosyncline.

Basement movements also were apparently responsible for widespread up-thrusting of basement wedges directed toward the Adelaide Geosyncline and the Gawler Craton. Decollement and diapiric deformation of basement cover was probably facilitated by a rise in temperature of incompetent cover rocks and vertical differential movement of basement blocks beneath the floor of the Geosyncline. Some of the buried basement blocks are outlined by faults that can be demonstrated, from stratigraphic evidence (Binks, 1968), to have originated contemporaneously with the Adelaidean sedimentation. The reactivation of the buried basement blocks was the cause of the confused fold-diapir-fault pattern that is evident today in the northern area of the Geosyncline. The Delamerian movements within the Geosyncline are confirmed by the widespread "overprint" of Lower Ordovician isotopic ages obtained by Compston et al. (1966), from Precambrian rocks within and marginal to the Geosyncline. The movements involved in the development of the peripheral northern and southern arcuate fold belts are conjectural. They probably involved deep-seated processes. Some basic rocks were intruded e.g., the Black Hill norite in the Kanmantoo Trough. The cross sectional shape of the fold belt is fan-shaped, as if vertical, rather than lateral forces, were the main contributors to the development of the fold belt (see Parkin, 1969, Fig. 43). Interpretation of the crustal events is difficult.

Hawkins et al. (1965) interpret the results of three marine reconnaissance seismic traverses, made in 1960, across the "continental margin" southwestward of Kangaroo Island. They found that the depth to the Mohorovicic discontinuity shallows from about 40 km under the continental plate of the Gawler Craton to 11-12 km under the ocean. The upper layer of the "oceanic crust" has a seismic velocity varying from 5.21 km/sec to 5.04 km/sec near the continental margin. They consider that a geological correlation with a 5.02 km/sec layer on the adjacent margin of the continental basement is doubtful. On the other hand Smith and Kamerling (1969), using refraction seismic and other data in connection with petroleum exploration, consider that the Duntroon Basin, which adjoins the "transition zone" of Hawkins et al. (*op. cit.*), is floored by rocks of the Kanmantoo Group and associated granite. This interpretation suggests that the Kanmantoo Group may extend across the "continental margin" into the ocean deep area.

CONCLUSION

The sequence of major tectonic events in South Australia which occurred in the period between early Carpentarian and Ordovician is summarized in Fig. 8. It is apparent that no single scheme for time-subdivision, using only one criterion such as isotopic dates or stratigraphic succession, is adequate. A scheme that embraces all criteria is sought. For the present, the Carpentarian and Adelaidean subdivision remain useful concepts within this part of Australia.

It is apparent that a great amount of mapping and isotopic dating remains to be done before individual fold belts in the basement in South Australia can be formally named. The use of terms such as "Willyamides", "Kimbarnides" and "Olarides" must be considered as being premature.

The hypothesis is presented that an extensive area of Australia was underlain by a plate of crystalline basement during the Archaean. The subsequent history has largely been that of fragmentation and reworking of this early craton of which the Gawler Craton remains as a relic late Carpentarian cratonic stage. This interpretation is difficult to reconcile with the concept of "ocean floor spreading" and "continental drift". The apparent displacement of the median ocean ridge south of Australia (Heirtzler et al., 1968) is not reflected in the internal structure of the

region of Australia considered in this paper. Some alternative mechanism such as foundering of continental crustal blocks in marginal ocean basin areas, as suggested by Beloussov (1969), should be considered.

ACKNOWLEDGEMENTS

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**SKRJABINOPTERA GOLDMANAE N. SP.
(NEMATODA : PHYSALOPTERIDAE)
FROM AN AUSTRALIAN AGAMID LIZARD**

*BY PATRICIA M. MAWSON**

Summary

Skrjabinoptera goldmani n. sp. is described from *Amphibolurus barbatus* from western New South Wales. The species is distinguished chiefly by the great development of the musculature of the pharyngeal part of the oesophagus.

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ABSTRACT

Skrjabinoptera goldmani n. sp. is described from *Amphibolurus barbatus* from western New South Wales. The species is distinguished chiefly by the great development of the musculature of the pharyngeal part of the oesophagus.

INTRODUCTION

Several collections of nematodes from the stomach of *Amphibolurus barbatus*, Cuvier, were made by Miss Judy Goldman, a postgraduate student at the University of Sydney, to whom I am most grateful. All the collections contained an apparently new species of physalopterid, for which the name *Skrjabinoptera goldmanae* is proposed. Most of the worms were firmly attached to the stomach wall by their anterior ends which were buried in the mucosa, so that some dissection was necessary to detach them. The hosts were taken in western New South Wales, around Cobar, Bobadah, and Nymagee.

Skrjabinoptera goldmanae n. sp.
(Figs. 1 to 10)

The males are 9.1 to 14.1 mm long, the females 16.0 to 23.0 mm.

A cuticular collar is present dorsally and ventrally but does not extend right round the anterior end. The two lateral pseudolabia each bear an apical tooth, two papillae, and an amphid. The apical tooth is directed outwards, and arises from a branched "anchor", apparently a cuticular thickening. Behind this on the inside of the lip are two cuticular inflations, one dorsally and one ventrally. The anterior end of the oesophagus is flattened from side to side and greatly widened dorso-ventrally forming two lateral masses connected to the body wall by radial fibres, probably part of the cephalic septum (Inglis, 1964). This enlargement of the oesophagus gives a characteristic appearance to the anterior end of the worm, which in lateral view widens and then is almost truncate. In the case of the older worms, which were most firmly attached to the host tissue, the anterior end is greatly stretched, the lips are turned outward, and a plug of the mucosa of the host extends well into the open buccal cavity (figs. 2, 6). Posterior to this enlarged pharyngeal part, the oesophagus is constricted, then widens rapidly, and is cylindrical to its posterior end. The length of the oesophagus is 2.9 to 4.8 mm in the male, 5.3 to 7.5 mm in the female, about a third that of the body. The nerve ring which surrounds it at the post-pharyngeal constriction is 400 to 540 μ from the anterior end of the worm in the male, 600 to 700 μ in the female.

In the male the cervical papillae are at about the same level as the nerve ring; in the female they lie a little in front of this. The excretory pore is a short distance behind the nerve ring.

The female reproductive system is typically physalopteran. There are four ovaries each leading by its oviduct to a small spherical swelling and thence to a uterus. The four ovaries are in the posterior third of the body. The four uteri unite in pairs a short distance behind the vulva, and the resulting tube enlarges

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slightly before entering the muscular vagina. The vulva is 6.5 to 10.5 mm, or $1/2.3$ to $1/3.1$ of the body length, from the anterior end.

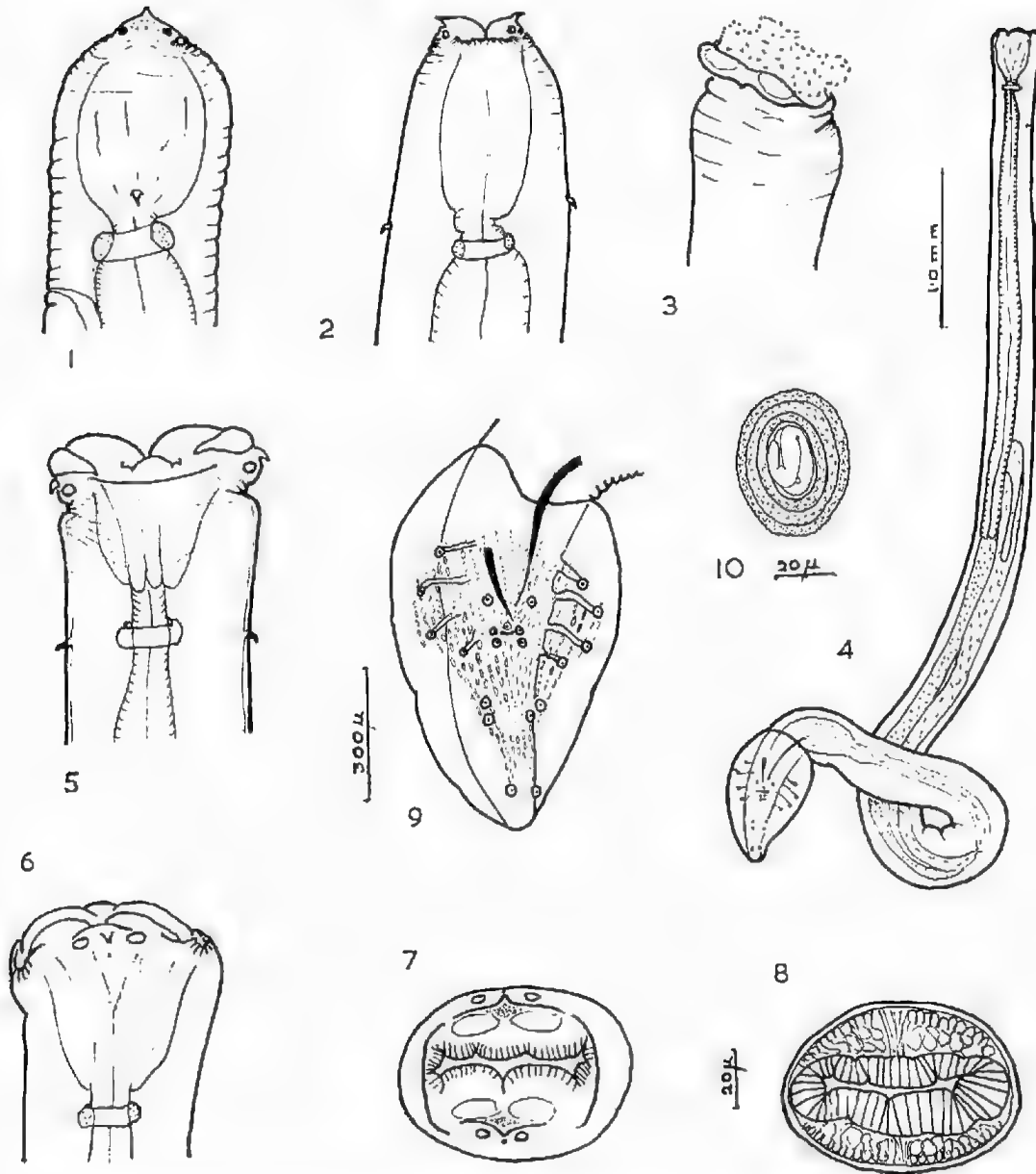
The eggs are thick-shelled, oval, 48 to 42 $\mu \times$ 30 to 35 μ , and those in the vagina and in the lower parts of the uteri are loosely contained in an outer envelope, apparently a little less densely chitinous than the egg shell proper, and embossed on the outer surface (Fig. 10).

In the male the caudal alae meet ventrally anterior to the cloaca; the embossed area on the ventral surface of the tail extends from the level of the most anterior caudal papillae to include all the caudal papillae, as shown in Fig. 9. The shorter right spicule (170-200 μ) is heavily chitinated, and tapers to a fine point; the left spicule (410-550 μ) is slender, very lightly chitinated, and also tapers to a point. The arrangement of the caudal papillae is shown in Fig. 9.

The species is placed in the genus *Skrjabinoptera* Schulz because each pseudolabium bears only one tooth. It differs from other species so far recorded for this genus in the great development of the pharyngeal part of the oesophagus. The specimens available come from at least seven host animals, all from the same general region, and vary from very young worms to large gravid females, and all show this characteristic development of the oesophagus, although only in the older specimens are the pseudolabia bent outwards and the collar region stretched.

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Figs. 1 and 2, anterior end of very young female, lateral and median views; 3, anterior end of older female, with plug of host's mucous membrane in mouth; 4, whole male worm; 5 and 6, anterior end of older male, ventral and lateral views; 7, en face view of head of female; 8, T.S. body just behind head, same specimen as Fig. 7; 9, ventral view of male tail; 10, egg from vagina.

Figs 1, 2, 5, 6 and 9 to same scale; Figs 3 to 4 to same scale; Figs 7 & 8 to same scale.

MALLEE VEGETATION OF THE SOUTHERN NULLARBOR AND ROE PLAINS, AUSTRALIA

*BY R. F. PARSONS**

Summary

The distribution and composition of mallee vegetation in the coastal strip from the Head of the Bight to Caiguna are described, and their relationship to soil and climatic factors discussed. All the eucalypts show marked gaps in their east-west spread. A distinctive sclerophyllous flora is described from siliceous sand topsoils in the western Roe Plain. This is surrounded by alkaline loamy soils, which may act as edaphic barriers isolating it from similar floras west of the Nullarbor Plain. The role of climate and sea level changes in producing the observed distribution is discussed. A plant species list for 14 mallee communities is appended.

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INTRODUCTION

Although mallee vegetation is known to occur in parts of the coastal strip from the Head of the Bight to Caiguna, Western Australia (Fig. 1), very little is known about its extent or nature (Tate 1879; Willis 1951, 1959).

The following introductory account is based on field work in November 1967, so that annual and ephemeral species are not dealt with. The strip from the coast to

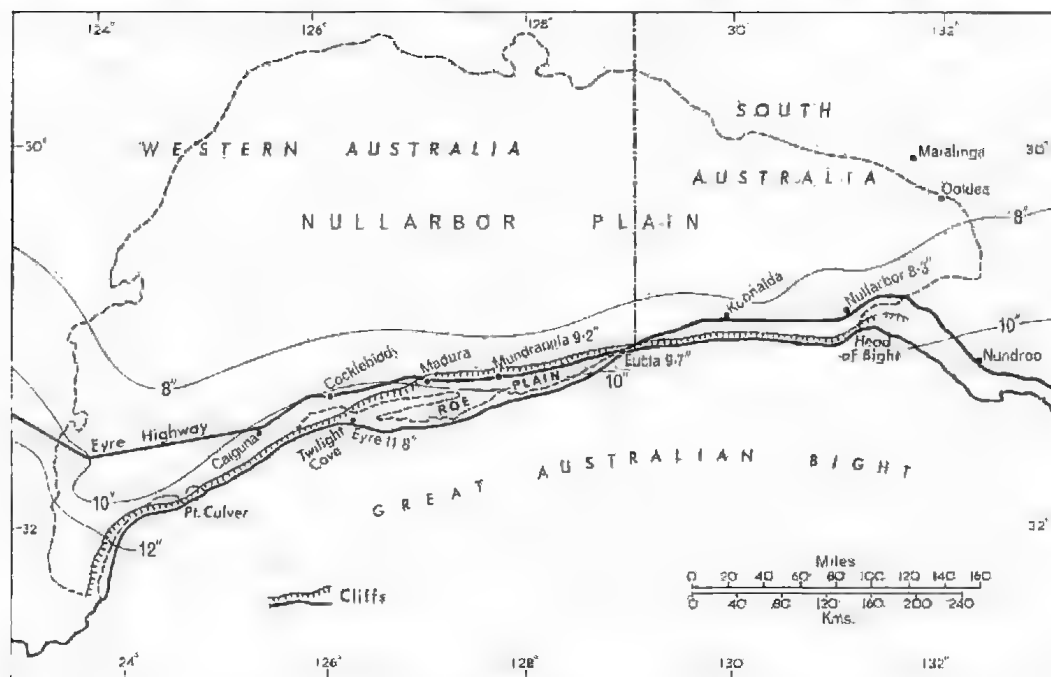


Fig. 1. The study area and its surroundings, showing the approximate margin of dunes (dashed line, from Jennings 1967), some mean annual isolyets, and annual rainfall means for the period 1902-1926 plus 1933-38 for four stations (Australia: Bureau of Meteorology).

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the northern-most limit of mallee vegetation was examined from the Head of the Bight in the east to Caiguna in the west by driving on most traversible tracks. Specimens of all plant species present were taken from the sites shown on Fig. 2 and were supplemented by limited collections from other areas. The species from



Fig. 2. The location of collecting sites listed in Appendix 1 and the location of sand dunes in the study area after Northcote *et al.* (1967, 1968) and Jennings (1967). Areas not shown as sand dunes are loamy soils on Tertiary limestone.

each site are listed in Appendix 1; the records of Willis (1951, 1965) from the cliffs behind Madura have been included (as site 10) for the sake of completeness. All specimens were identified by, and are lodged at, the State Herbarium of South Australia, except for *Eucalyptus diversifolia*, specimens of which have been retained by the author. All specimens of *E. foecunda*, *E. oleosa*, *E. socialis* and *E. rugosa* were checked by D. F. Blaxell and L. A. S. Johnson.

GEOMORPHOLOGY

The study area comprises the Roe Plain and the southern margin of the Nullarbor Plain, if the latter is defined geologically and topographically (Jennings 1963) and not botanically. In this region the Nullarbor is a very flat plain of Miocene limestone (the Nullarbor limestone), except where it is covered with dunes of aeolian calcarenite around Twilight Cove (Fig. 2; Jennings 1967). The Roe Plain is about 200 feet lower than the Nullarbor Plain, is separated from it by a scarp called the Hampton Range and is floored with Eocene limestone. Dunes of three different ages occupy most of the westward end and a seaward fringe; Jennings *loc. cit.*

CLIMATE

The area has a dry Mediterranean type climate (Fig. 3), with mean annual rainfall increasing southwards (Fig. 1). Percentage mean variability from mean annual rainfall is greater than 20% and the rain comes mostly as light showers; mean rainfall per wet day is less than 0.2 in (5 mm) (Leeper 1960).

SOILS

Most of the area is covered by loamy, calcareous, alkaline soils formed on Tertiary limestone, and are usually less than 60 cm deep (Northcote *et al.* 1967;

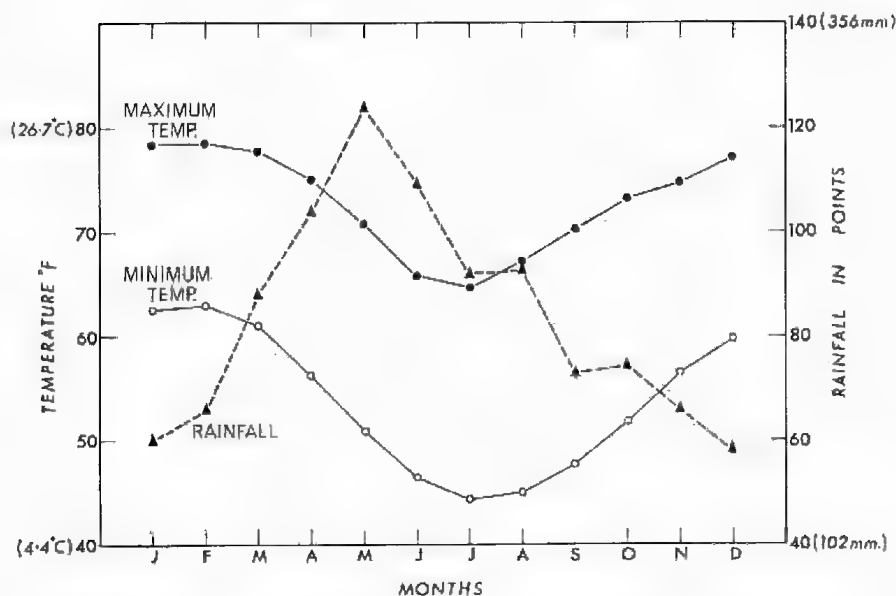


Fig. 3. Mean monthly rainfall and maximum and minimum screen temperatures at Eucla. Data from Australia; Bureau of Meteorology (1956).

Northcote *et al.* 1968). However, there are also large areas of dunes (Fig. 2) of various types and ages. The young dunes nearest the coast were of calcareous beach sand, except at Twilight Cove, where the sand is white and siliceous with a very small shell content. The beach sands further west, past Point Culver, appear to be siliceous also (Northcote *et al.* 1967). There are at least two types of older dunes. Deep calcareous sandy types (Table 1 Site 7) were the only ones seen in the eastern Roe Plain (Sites 5 & 7), while dunes of siliceous sand over aeolian calcarenite (Table 1 Site 11) were the only ones seen in the west (Sites 8, 9 and 11). Much more work is necessary before the distribution of each type can be mapped.

TABLE 1

Description of two dune soils in the study area.

Site 7		
Depth (cm)	Colour	Description
0-13	pale brown	Calcareous loamy sand with small CaCO_3 nodules
13-38	pink	Calcareous loamy sand with small CaCO_3 nodules
38-140	pink	Calcareous loamy sand with more frequent CaCO_3 nodules
140-152	very pale brown	Calcareous sand with CaCO_3 nodules and shell fragments
Site 11		
Depth (cm)	Colour	Description
0-10	pale brown	Sand
10-51	very pale brown	Sand
51-66	yellow	Sand
66-		Sheet limestone

BIOTIC INFLUENCES

The introduced rabbit (*Oryctolagus cuniculus*) is the most common grazing mammal in the area; in 1947, thirty-five trappers were able to trap up to 20,000 rabbits a week in the Cocklebiddy area (Morrison 1948). An abundance of rabbits made commercial hunting still profitable in 1967. Rabbits are almost certain to have very adverse effects on the seedling regeneration of mallee eucalypts (Parsons 1968) and that of many other plants (Hall, Specht and Eardley 1964) in this area.

Native animals are discussed by Tate (1879) and McEvey and Middleton (1968), while sheep and cattle grazing has occurred in the area since the 1870's (Dunkley 1967). Hundreds of tons of bitter quandong (*Santalum* sp.) have been cut from the area for incense making and timber (Brown 1919). Large-scale fires do not occur in the mallee and this area; mallee fires occur only on very hot days and burn out only a few acres (pers. comm., Harvey Gurney, Eucla).

DISTRIBUTION OF MALLEE VEGETATION

The term mallee vegetation is used here to include all communities dominated by mallee species of *Eucalyptus*. The distribution of mallee vegetation in the South Australian part of the study area based on field traverses is shown in Fig. 4.

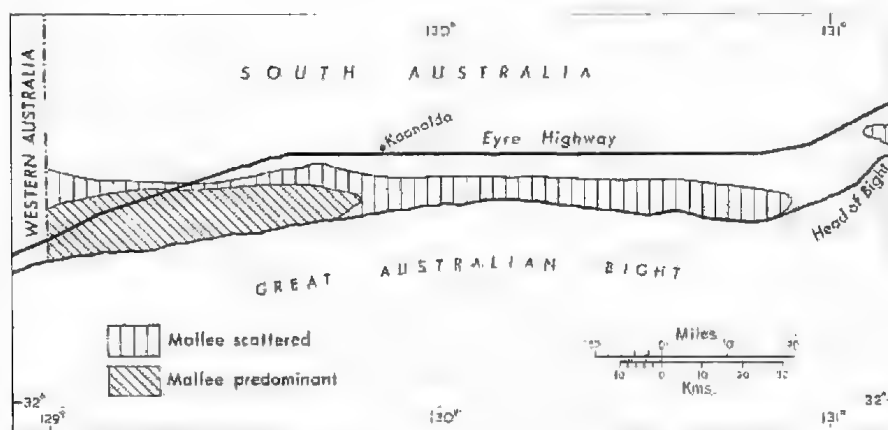


Fig. 4. Approximate distribution of mallee vegetation in the South Australian part of the Nullarbor Plain, "Mallee predominant" indicates 50% or more of the area carries mallee eucalypts; "mallee scattered" indicates less than 50% of the area carries mallee eucalypts.

A vegetation map of the Western Australian part of the area will be published shortly by Dr. J. S. Beard, King's Park and Botanic Gardens, Perth. All that needs to be said here about the Western Australian sector, is that (1) Mallee is predominant along the top of the entire Hampton Range but thins out north of this and disappears at about 20 miles (32 km) north of the Eyre Highway. (2) Mallee is predominant on all that part of the Nullarbor Plain west of Madura and south of the Eyre Highway. (3) Mallee is predominant in the western part of the Roe Plain, but becomes increasingly scattered, and almost confined to a narrow coastal strip, towards the east.

All the mallee on the southern Nullarbor Plain is in areas wetter than 8 inches (20 cm) mean annual rainfall. Mallee eucalypts occur all the way between the large mallee areas in Western Australia and Eyre Peninsula except for a complete break of 16 miles (26 km) west of the Head of the Bight, the driest part of the southern Australian coastline, where mean annual rainfall is probably slightly greater than 8.3 in (210 mm), the rainfall at Nullarbor.

Mallee is usually predominant in areas wetter than about 10 in (250 mm) mean annual rainfall. The absence of mallee from large areas in the east of Roe Plain, while it occurs to the north in presumably drier areas along the Hampton Range is difficult to explain. Much more rainfall and soil data are obviously necessary.

In the wetter south-west of the Roe Plain, mallee is widespread on the shallow loamy soils on Tertiary limestone and on dunes of all ages. In drier parts of the Plain, especially in the east, it tends to be more common on sandy dune soils because these are likely to supply more water to plants in this area than the loamy ones (Rowan and Downes 1963).

In general, mallee occupies the wettest parts of the Nullarbor and Roe Plains; in drier areas it is replaced by a variety of vegetations, including *Acacia sowdenii* woodlands and shrub steppe (Willis 1951, 1959).

STRUCTURAL TYPES DOMINATED BY MALLEE EUCALYPTS

(a) *Heath*

Although Fig. 4 shows "mallee predominant" at the coast, both here and at the coast south of Caiguna, there is a zone of heath (Wood and Williams 1960) for about 500 feet (160 m) behind the sea cliffs from which eucalypts are absent. Landward from this is a zone of heath from $\frac{1}{2}$ –1 mile (800–1600 m) wide containing mallee eucalypts up to 5 feet (1.5 m) high. *Melaleuca lanceolata* is common and often dominant in this heath, for which floristic lists are given in Appendix 1 (Site 1, 2 and 13). Asymmetric growth forms and leaf tip necrosis suggest that wind-borne salt spray is important in maintaining the low stature of this vegetation (Parsons and Gill 1968) and high evapotranspiration caused by wind exposure is probably also effective. Landward from the heath, taller mallee eucalypts become dominant (see also Tate 1879).

(b) *Semi-Arid Mallee*

This sub-form of Wood and Williams (1960) is widespread on the loamy soils of the Nullarbor and the Roe Plain. In fact, except for the coastal heaths, this was the only mallee vegetation found in such soils to about as far west as Cacklebiddy. Height of the eucalypts ranges from 5 feet (1.5 m) where the sub-form grades into heath, to about 30 feet (9 m). *Melaleuca quadrifaria* is a frequent co-dominant with the eucalypts to at least as far east as a point 16 miles (26 km) east of the South Australian border (Plate 1 (a)). *M. lanceolata* is a common large shrub and *Cratystylis conocephala* the most widespread small shrub, usually occurring with a large number of chenopods (Appendix 1, Sites 3 and 4). This type of semi-arid mallee is also found on old dunes (Site 5). Another type found on dunes on the Roe Plain has a denser eucalypt stratum and a sparse understorey dominated by *Rhagodia preissii* (Sites 7 and 12). A third type seen is found on the scarp of the Hampton Range (Site 6).

Lastly, a distinctive type with an understorey dominated by *Triodia* cf. *scariosa* is found both on sandy dune soils (Site 9) and in small patches on loamy soils on the Nullarbor Plain south of Cacklebiddy and Caiguna.

(c) *Sclerophyll mallee*

This sub-form of Wood and Williams (1960) was found on dunes on the western Roe Plain as far east as site 8 south of Madura. The dunes carry mallee eucalypts and scattered trees of *Callitris verrucosa* up to 15 feet (4.5 m) high with a dense understorey (Plate 1 (b)) containing sclerophyllous shrubs like *Hakea nitida* and *Beaufortia empetrifolia* (Appendix 1, Sites 8 and 11). This type was found only on dune soils of siliceous sand over limestone (Table 1).

On the Nullarbor limestone from 6 miles (10 km) south of Caiguna, to the coastal heath, sclerophyll mallee with a dense understorey dominated by *Casuarina helmsii* occurs (Site 14, Plate 1 (c)). It also appears on such soils from 6–11 miles (10–18 km) south of Cocklebiddy. Thus this type occurs on the wettest areas of Nullarbor limestone examined. In drier areas it grades into semi-arid mallee with *Cratystylis conocephala* as the dominant shrub.

DISTRIBUTION OF *EUCALYPTUS* SPECIES(a) *Eucalyptus socialis*

This is the species whose southern Nullarbor and Roe Plains representatives were known as *E. transcontinentalis* or *E. oleosa* var. *glauca* before the work of Brooker (1968). It has the driest lower rainfall limit of the eucalypts in the area, as it extends farthest to the north and west in that part of the Nullarbor Plain studied (Fig. 5). In all such marginal areas examined, a band of *E. socialis* was the northern or westernmost mallee found. Thus a more or less continuous zone, where *E. socialis* is the only eucalypt, may enclose the wetter mallee areas, where *E. socialis* and other eucalypts occur. The only known break in its east-west distribution is one of 16 miles (26 km) just west of the Head of the Bight (Table 2).

(b) *E. oleosa*

This taxon was generally known as both *E. oleosa* and *E. oleosa* var. *angustifolia* before the work of Brooker (1968). It occurs on the Nullarbor and Roe Plains to at least as far east as Koonalda (Fig. 5). It is rare south of Koonalda, and may not occur much further east, giving a maximum possible break in distribution of about 52 miles (82 km) before it reappears on sandy soils near the Head of the Bight (Table 2). No other definite east-west breaks are yet known in the area.

TABLE 2

Edaphic range and degree of discontinuity for a number of trees species. 'Discontinuity' indicates maximum possible size of main gap in east-west distribution in the Nullarbor Plain area.

Species	Soil			Discontinuity miles (km)
	Loams on limestone	Deep calcareous sand	Siliceous sand*	
<i>Eucalyptus socialis</i>	X	X		16 (25)
<i>E. oleosa</i>	X	X	X	52 (82)
<i>E. gracilis</i>	X	X	X	64 (102)
<i>E. dumosa</i>				
complex	X	X	X	163 (245)
<i>E. incrassata</i>			X	268 (429)
<i>E. foecunda</i>	X		X	372 (595)
<i>E. diversifolia</i>	X		X	312 (499)
<i>E. cooperana</i>			X	Not applicable

* Includes siliceous sand over limestone.

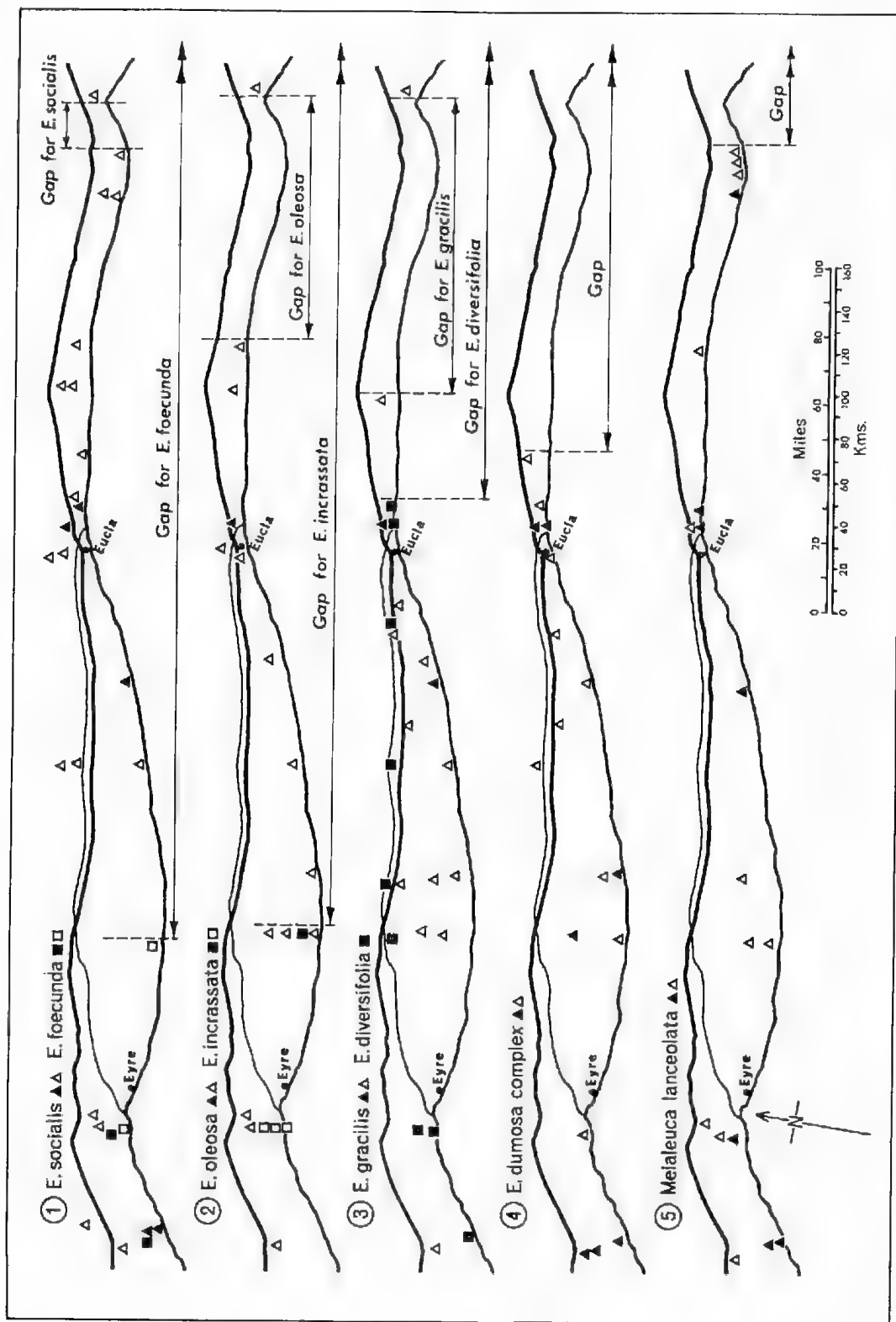


Fig. 5. Distribution of eight species in the study area, showing known gaps in east-west spread. Closed symbols for herbarium records, open symbols for field identifications. Coarse line shows Eyre Highway.

The extension of *E. socialis* into areas drier than those supporting *E. oleosa* in the present study seems to occur elsewhere too. Thus in New South Wales *E. socialis* extends much further north of the 10 in. (25 cm) mean annual rainfall isohyet than *E. oleosa* (pers. comm., M. I. H. Brooker, Western Australian Herbarium, Perth), and in South Australia at Chowilla Station (mean annual rainfall 8.5 in (22 cm)), *E. socialis* is found (Kuchel 1967) noted as *E. transcontinentalis* while *E. oleosa* does not occur before wetter areas are reached.

(c) *E. gracilis*

Although this species was not found on the Nullarbor Plain in areas drier than about 9 in. (23 cm) mean annual rainfall, it is recorded from sandy areas north of the Plain around the 7 in. (18 cm) isohyet (Ford and Sedgwick 1967).

(d) *E. dumosa* complex

This group is in need of taxonomic revision (Burbidge 1947) so no attempt was made to identify the complex to species level in the field. Herbarium specimens taken were identified as *E. brachycalyx*, *E. conglobata* and *E. rugosa* (see Appendix 1 for distribution). This complex has not been found on the Nullarbor more than 28 miles (45 km) east of Eucla, nor during a very brief inspection of the sandy country at the Head of the Bight. The nearest eastern record seems to be an *E. dumosa* complex specimen (FRI 17848) from 15 miles (24 km) west of Nundroo.

The wetter lower rainfall limit of the *E. dumosa* complex than *E. socialis*, *E. oleosa* and *E. gracilis* found in this study has also been noticed elsewhere (Jessup 1948).

(e) *E. incrassata*

This name is used to include the varieties *costata* and *angulosa*. It was not found anywhere east of Madura, and the nearest eastern record is that of Cleland (1966), 30 miles (48 km) east of White Well. The record of *E. incrassata* near Eucla cited by Willis (1951, 1959) and McEvey and Middleton (1968) is now known to be an error; the specimen is *E. dumosa* complex (pers. comm., G. Chippendale, Forest Research Institute, Canberra). The occurrence of *E. incrassata* only on sand topsoils (Table 2), in dry areas around its lower rainfall limit has been noted in other areas (Parsons and Rowan 1968). Its general distribution has been discussed elsewhere (Parsons 1969).

(f) *E. foecunda*

Like *E. incrassata* it was not found east of Madura; in this case the nearest record to the east appears to be near Koonibba (Cleland 1966 as *E. leptophylla*) giving a gap of 372 miles (595 km). It has been recorded on finer-textured soils than *E. incrassata* both in this study (Table 2) and elsewhere (Parsons and Rowan 1968). This suggests a definite difference between the two species in edaphic range, despite their frequent occurrence together in many areas (Litchfield, 1956).

(g) *E. diversifolia*

This species is dealt with by Parsons (1969), and will not be discussed further here.

(h) *E. cooperana*

This Western Australian species was only found throughout the area of siliceous sand over aeolian calcarenite north of Twilight Cove (Plate 1 (d)).

This is the eastern-most locality from which the species has been recorded (Gardner 1961).

(4) *E. micranthera*

This Western Australian species appears to be the only other eucalypt recorded from the area (from near Eyre by Gardner 1960); it was not found during the present study.

DISTRIBUTION OF *MELALEUCA LANCEOLATA*

The distribution of *M. lanceolata* was carefully noted to supplement the valuable introductory accounts of its distribution given by Willis (1948) (as *M. pubescens*), and Blake (1968). Intensive work has reduced the 170 mile (272 km) distribution gap east of Eucla recorded by Willis (1948) to 70 miles (112 km) (Fig. 5). Along the Nullarbor coast *M. lanceolata* is found in the driest areas in which mallee eucalypts occur and this is also true at Koonamore Station (Carradus, Specht and Jackman 1965); elsewhere it seems to be absent from the driest mallee areas (Jessup (1948) as *M. pubescens*).

DISCUSSION

The eucalypts show two main types of distribution. *E. socialis*, *E. oleosa*, *E. gracilis* and the *E. dumosa* complex are frequent and widespread through most of the mallee area, while *E. incrassata*, *E. foecunda* and *E. cooperana* are found only where mean annual rainfall exceeds about 11 inches (28 cm).

Eucalypt distribution on the siliceous sands shows some interesting features. The driest area of siliceous sands examined carried *E. oleosa*, *E. gracilis* and the *E. dumosa* complex (Site 9). In wetter areas, such soils carried *E. incrassata*, *E. foecunda* and *E. cooperana* (Sites 8 and 11). *E. incrassata* and *E. cooperana* were only recorded on siliceous sands, which may be because sands are likely to be better water suppliers to plants in this climate than the much more widespread loams.

However, the role of soil chemical factors also needs to be considered. Are any other species found only on siliceous sands and not on the more alkaline loams? The sclerophyllous flora of the siliceous sand area is much richer in species than the surrounding flora on loam soils, and 27 plant species were found only on siliceous sand and not on the wetter loam country south of Caiguna (Appendix 1). Many of these 27 species seem to occur principally on siliceous sand plain areas west of the Nullarbor (Beard, no date). It is possible that many of these species are unable to tolerate soils as alkaline as the loams on limestone. If so, then much of the flora of the siliceous sand areas of the western Roe Plain is completely isolated from similar areas by edaphic barriers:—the large expanses of loams on limestone of the Nullarbor and Roe Plains.

South west of Twilight Cove, the Nullarbor limestone continues for about 65 miles (104 km) before sand dunes are reached near Pt. Culver. Some of these dunes are known to be siliceous (Fig. 2) but the sands near Pt. Culver are poorly known botanically.

The simplest hypothesis to account for the apparently isolated species occurrences on siliceous sand in the western Roe Plain is to postulate a continuous strip of siliceous sand topsoils linking the Roe Plain with siliceous sand areas further west during Quaternary low sea levels. This could provide continuous species distributions which were subsequently fragmented by rising sea levels (Parsons 1969).

This hypothesis could account for the occurrence of many of the species confined to siliceous sand in the western Roe Plain. One notable exception is

Spyridium spathulatum, known elsewhere in Western Australia only from the Rawlinson Range.

Of the two eucalypts which were only recorded from siliceous sand, *E. incrassata* is known from shallow loamy soils on limestone in wetter areas elsewhere (Litchfield 1956), while *E. cooperana* appears only to have been recorded from sandy non-calcareous topsoils, both in the Roc Plain and elsewhere.

Discontinuities in the east-west spread of all the eucalypts were noted. As all except *E. cooperana* have been recorded on shallow loams on limestone (Table 2; Litchfield 1956), there are probably no edaphic barriers to the spread of these other species in the area. The known gaps in distribution (Table 2) coincide with the driest parts of the coastline. A habitat suitable for continuous east-west distribution of these species could thus be provided by an increase in effective rainfall. Alternatively, lower sea levels in the Last Glacial would produce a coastal lowland south of the present coast and in a wetter latitude (Parsons 1969), which may have provided a suitable habitat.

Although attention has been focused here on major gaps in the east-west spread of the species, there are a number of interesting disjunct occurrences to the north of the study area; *E. foecunda* at Ooldea and Tarcoola (Burbidge (1947) as *E. leptophylla*), *E. dumosa* complex at Maralinga and *Melaleuca lanceolata* at Ooldea (Willis 1948). The significance of these must await further study.

ACKNOWLEDGEMENTS

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POACEAE

- Agrostis* sp.
Amphipogon cf. *turbinatus* R.Br.*-
Danthonia caespitosa Gaudich.
Stipa acrociliata Reader
S. drummondii Steud.
S. eremophila Reader
S. hemipogon Benth.
S. scabra Lindl.
S. verticillata Nees ex Spreng.
Triodia scariosa cf. Burbidge

CYPERACEAE

- Gahnia lanigera* (R.Br.) Benth.
Lepidosperma drummondii Benth.*
Schoenus armeria Boeckl.*-
S. lanatus Labill.*+
S. nitens (R.Br.) Poir.†
Schoenus pleiostemoneus F v M.*+

RESTIONACEAE

- Loxocarya flexuosa* (R.Br.) Benth.*+

LILIACEAE

- Bulbinopsis semibarbata* (R.Br.) Borzi
Dianella revoluta R.Br.
Lomandra glauca (R.Br.) Ewart
Tricoryne elatior R.Br.†

CASUARINACEAE

- Casuarina helmsii* Ewart & Gordon
C. huegelianu Miq.*

PROTEACEAE

- Adenanthos sericea*
 Labill. var. *brevifolia* Benth.†
Grevillea cf. *pinaster* Meissn.*†
G. sparsiflora F v M.*
Hakea nitida R.Br.*†

SANTALACEAE

- Etocarpus aphyllus* R.Br.
E. sparteus R.Br.
Santalum acuminatum (R.Br.) A.DC.

LORANTHACEAE

- Amyema miquelii* (Lehm. ex Miq.) Tiegh.

CHENOPODIACEAE

- Arthrocnemum halocnemoides* Nees
Atriplex acutibractea Anderson
A. hastata L. var. *salina* Wallr.
A. hymenotheca Moq.*
Bassia patentiuscuspis Anderson
B. uniflora (R.Br.) F v M.
Encyphaena tomentosa R.Br.
Kochia erioclada (Benth.) Gauba
K. excavata var. *trichoptera* Black
K. plurifolia F v M.
K. sedifolia F v M.
K. villosa Lindl.
Rhagodia crassifolia R.Br.
R. preissii Moq.
Threlkeldia diffusa R.Br.

AMARANTHACEAE

- Ptilotus obovatus* (Gaudich.) F v M.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14 A
<i>Agrostis</i> sp.						h									
<i>Amphipogon</i> cf. <i>turbinatus</i> R.Br.*-											h			h	
<i>Danthonia caespitosa</i> Gaudich.	h		h												
<i>Stipa acrociliata</i> Reader					h										
<i>S. drummondii</i> Steud.						h									
<i>S. eremophila</i> Reader							h								
<i>S. hemipogon</i> Benth.															
<i>S. scabra</i> Lindl.			h	h											
<i>S. verticillata</i> Nees ex Spreng.										w					
<i>Triodia scariosa</i> cf. Burbidge									h						
<i>Gahnia lanigera</i> (R.Br.) Benth.								h	h		h		f	h	
<i>Lepidosperma drummondii</i> Benth.*									h		h				
<i>Schoenus armeria</i> Boeckl.*-							h								
<i>S. lanatus</i> Labill.*+											h				
<i>S. nitens</i> (R.Br.) Poir.†											h				
<i>Schoenus pleiostemoneus</i> F v M.*+											h				
<i>Loxocarya flexuosa</i> (R.Br.) Benth.*+												h			
<i>Bulbinopsis semibarbata</i> (R.Br.) Borzi	h						f	h		f					
<i>Dianella revoluta</i> R.Br.															h
<i>Lomandra glauca</i> (R.Br.) Ewart								h			h				
<i>Tricoryne elatior</i> R.Br.†															
<i>Casuarina helmsii</i> Ewart & Gordon											f			h	
<i>C. huegelianu</i> Miq.*														n	
<i>Adenanthos sericea</i>											n				
Labill. var. <i>brevifolia</i> Benth.†											h				
<i>Grevillea</i> cf. <i>pinaster</i> Meissn.*†															h
<i>G. sparsiflora</i> F v M.*															
<i>Hakea nitida</i> R.Br.*†								h			f				
<i>Etocarpus aphyllus</i> R.Br.		h	f				h							n	h
<i>E. sparteus</i> R.Br.															
<i>Santalum acuminatum</i> (R.Br.) A.DC.						h									
<i>Amyema miquelii</i> (Lehm. ex Miq.) Tiegh.										h					
<i>Arthrocnemum halocnemoides</i> Nees					h	h									
<i>Atriplex acutibractea</i> Anderson				h				h							
<i>A. hastata</i> L. var. <i>salina</i> Wallr.															
<i>A. hymenotheca</i> Moq.*						h									
<i>Bassia patentiuscuspis</i> Anderson				h		h		f							
<i>B. uniflora</i> (R.Br.) F v M.	h			h											
<i>Encyphaena tomentosa</i> R.Br.	h	h				h									
<i>Kochia erioclada</i> (Benth.) Gauba	h		h			h									
<i>K. excavata</i> var. <i>trichoptera</i> Black															h
<i>K. plurifolia</i> F v M.		h													
<i>K. sedifolia</i> F v M.	h														
<i>K. villosa</i> Lindl.	h														
<i>Rhagodia crassifolia</i> R.Br.							h								h
<i>R. preissii</i> Moq.								h		h	w	h			
<i>Threlkeldia diffusa</i> R.Br.		h	h			h	h								h
<i>Ptilotus obovatus</i> (Gaudich.) F v M.							h								

[illegible]

EXPLANATION OF PLATE

PLATE 1

- (a) Tall semi-arid mallee on the Roe Plain 14 miles (22 km) south of Moodini. *Eucalyptus gracilis* on right; *Melaleuca quadrifaria* on left and in background. Figure is six feet tall.
- (b) Sclerophyll mallee about 12 feet (4 m) high at Site 11. *Eucalyptus diversifolia* on left; *Callitris verrucosa* on right.
- (c) Sclerophyll mallee about 8 feet (2.7 m) high at Site 14. *Eucalyptus socialis* and *Casuarina helmsii* are clearly visible.
- (d) A stand of *Eucalyptus cooperana* 1 mile (1.6 km) south of site 11, showing the characteristic, starkly white stems.



(b)



(d)



(a)



(c)

CANOPY DYNAMICS OF TREES AND SHRUBS WITH PARTICULAR REFERENCE TO ARID-ZONE TOPFEED SPECIES

BY J. R. MACONCHIE AND R. T. LANGE†*

Summary

A study is reported in which foliage gain and loss was followed in canopies of tree and shrub populations. Data are presented tracing concurrent quantities and rates of leaf gains and losses in stands of five arid-zone topfeed species in stands at Yudnapinna, South Australia, during the period May 1965 to January 1967. These data are examined also with reference to time of year and rainfalls, which occurred during the period.

The performances of the five species are grouped into three categories characterized with respect to various features such as number of phases, synchronization of foliation and defoliation, and seasonal periodicity. The significance of both method and results in revealing canopy dynamics in arid regions is discussed.

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INTRODUCTION

Topfeed or browse species are those trees and shrubs in rangeland vegetation which produce stock fodder. Some of this foliage is directly accessible to stock, some is shed to the ground. Mulga (*Acacia aneura* F.v.M.), bullock-bush (*Heterodendrum oleaeifolium* Desf.) and plum-bush (*Santalum lanceolatum* R.Br.) are typical Australian examples.

The pastoral importance of topfeeds is recognized and has been extensively discussed; for example, in Joint Publication 10 of the Imperial Agricultural Bureaux it was pointed out that "probably more animals feed on shrubs and trees, or on associations in which shrubs and trees play an important part, than on true grass or grass-legume pastures, short and tall-grass ranges, and steppes". Topfeeds certainly have importance in the Australian arid-zone.

With few exceptions, published data about canopy growth and hence fodder production by topfeed stands in the Australian arid-zone are lacking.

Principles for determining productivity of tree stands are well established (Ovington, 1962). Methods refer mostly to forest and agricultural situations where sites, climates and stands are closely specified, cyclic and predictable, and emphasize mean production of timber by weight or volume, or total yield by weight or calorific equivalent. In the Australian arid zone, stands are not closely specifiable because their biology is not well understood, and climate is neither cyclic nor predictable in many important respects. Further, emphasis regarding topfeeds is on foliage alone, and preconceptions, like prior literature on these topfeeds, are absent. It is necessary to adopt an approach consistent with this context. Such an approach, implemented in this study, has yielded relevant data about production rates of arid-zone topfeed species, and this paper reports and discusses the approach itself and results obtained by its use.

METHODS

For each species the study unit was the accessible outer foliage of the natural stand, regarded as a population of shoots. This population was sampled by

* Animal Industry Branch, Northern Territory Administration, Alice Springs, N.T.

† Department of Botany, University of Adelaide, South Australia.

restricted randomization, that is, the total stand was first sectorized and then random samples were drawn pro rata from each sector. A tag was affixed on each sampled shoot axis between the sixth and seventh leaf or leaf-bearing position proximal to the apex. Between 100-150 samples were tagged per stand. Total leaf number distal to tags was regarded as initial capital or quantity, susceptible to gain and loss. Records were kept of leaves and leaf-bearing positions on individual shoots; changes in leaf numbers were thus observed and recorded at intervals during a protracted period. The use of tags for this purpose is well known (Nelson 1930, Njoku 1963).

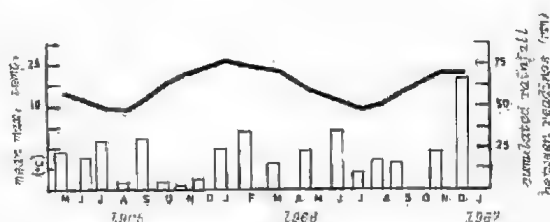


Fig. 1: Shows mean maximum daily temperature ($^{\circ}\text{C}$) and accumulated rainfalls (mm) for successive periods.

Experimental sites were located on Yudnapinna Station (an arid-zone pastoral lease in South Australia) at lat. 32.2°S , long. 137.5°E , in vegetation described by Jackson (1958), who also described associated climate, physiography and soils. Climatic data for the period were obtained from the Yudnapinna records of the Commonwealth Bureau of Meteorology. The species studied were *Acacia sowdenti* Maiden, *Myoporum platycarpum* R. Br., *Heterodendrum oleae-folium* Desf., *Cassia nemophila* var. *coriacea* (Benth.) Symon and *Cassia nemophila* var. *platypoda* (R. Br.) Benth. Voucher specimens are deposited in the State Herbarium of South Australia.

RESULTS

Summarized data are presented in figures 2 and 3. Figure 2 shows the course of cumulative leaf gain, cumulative loss, and cumulative gain/loss balance for each of the five species; Figure 3 shows rates of gain and loss for each of the five species. Figure 1 shows graphs of mean maximum daily temperature, and accumulated rainfalls for successive periods, in the study area.

The five species fall into three categories on differences and similarities of performance.

Category I

A. The *Heterodendrum oleae-folium* stand (Figs. 2d; 3a).

Observations began in April 1965. No changes occurred until August, after mean temperatures rose from their winter low. Foliation and defoliation then occurred at more or less equivalent low rates until November, after which rates increased until February 1966. Net gain within samples was then about 25%. With the passing of peak summer temperatures, foliation rates fell to near zero by September, as did defoliation rates. From February to October 1966 net foliage declined by about 20%. Again when temperatures began to rise in

summer, rates of foliation and defoliation increased until December and began to decline by January 1967. Net gain to initial capital was about 75% when observations ended.

The following points are established:

- (a) This stand exhibited canopy dynamics which appear to be cyclic on a seasonal basis. (In this locality rainfall is not seasonal hence "season" implies only temperature and photoperiod cycles.)
- (b) The characteristics of these canopy dynamics were (i) rates which increased rapidly in spring from near zero, sustained high values until thermal midsummer, then declined gradually to very low rates by thermal midwinter; (ii) synchronous and similar rate changes in foliation and defoliation; (iii) the differences in the magnitude of these rates caused net increases in the period November to February, with little change or slight decline over intervening periods.
- (c) Foliation and defoliation rates changed irrespective of rainfalls, and showed no direct response to rainfalls.

B. The *Acacia sowdenii* stand (Figs. 2b; 3b).

The performance in this stand was generally similar to that in the *Heterodendrum oleaefolium* stand regarding cyclic rate changes, no obvious reaction to rainfalls, and net losses during winter. There are however differences in particulars, namely (i) curve inflexions occurred later in summer, (ii) foliation and defoliation rate changes were not well synchronized, and (iii) a higher net gain was attained over the period.

Category II

The *Myoporum platycarpum* stand (Figs. 2c; 3c).

This performance, like those in category I, showed no direct reaction to rainfalls, but differed in that higher rates of foliation were sustained longer and rate changes were gradual rather than sharp. Net gains were sustained during the entire period, and ultimate net gains were considerably higher than in Category I. Since all curve inflexions were relatively suppressed, so was expression of foliation/defoliation synchronization, and apparent seasonal cycle.

Category III

A. The *Cassia nemophila* var. *platypoda* stand (Figs. 2a; 3d).

This performance differed markedly from those of other categories in that three phases of rate-change occurred during the period where other performances exhibited only two. Rainfalls were the only non-seasonal environmental variables measured; there was no obvious relationship between the timing of these and the middle phase of rate-change. Substantial nett loss occurred between the last two phases of rate-change. There was no close relationship between rates of foliation and defoliation. Overall net gain was comparable with Category II.

B. The *Cassia nemophila* var. *coriacea* stand (Figs. 2e; 3e).

This performance was essentially similar to that of *Cassia nemophila* var. *platypoda*, viz.: three phases of rate change instead of two. Net loss was sustained between the first two of these; overall net gain was lower.

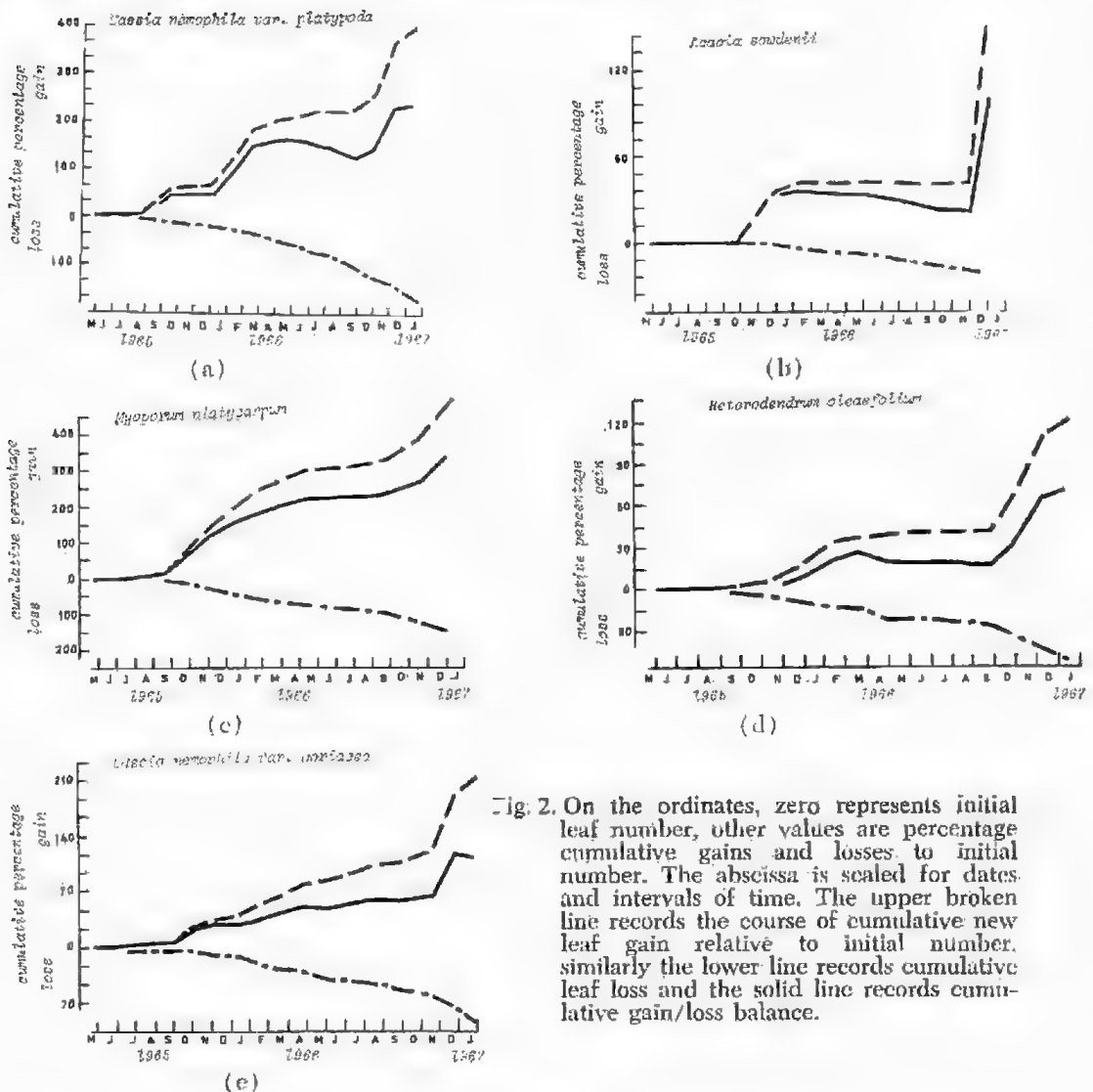


Fig. 2. On the ordinates, zero represents initial leaf number, other values are percentage cumulative gains and losses to initial number. The abscissa is scaled for dates and intervals of time. The upper broken line records the course of cumulative new leaf gain relative to initial number, similarly the lower line records cumulative leaf loss and the solid line records cumulative gain/loss balance.

DISCUSSION

The first noteworthy feature is that of apparent seasonal regularity in the way some species gain and shed leaf. There are two aspects to this, first, rainfall (8 in. annual average in the area) is erratic and, apart from slight elevation about February, monthly averages over 30 years are about equal; second, apparent cycles of growth coincide with the build up and climax of high summer temperatures and related water-stress. This situation parallels that in Dark Island Heath (Specht 1957), where main growth is in summer at times of soil water depletion. As opposed to such heath, these Yudnapinna stands are not even guaranteed a predictable wet winter. Such growth phenomena remain unexplained.

The second important feature is variation in performance between stands. If eventual consideration be given to the informed use of arid-zone topfeeds, attention must be directed then to the implications of this variation. Thus the timing

of Category I production phases appeared to be predictable from a knowledge of date alone, and independent of the timing of particular rainfalls. This predictability attached, in *Heterodendrum oleaeifolium* for example, to both fresh leaf production and litter drop. Category III stands, in contrast, represented a different kind of topfeed, since they displayed three phases of activity versus two for other species in their immediate vicinity. The Category II species represented yet another type, where leaf gain proceeded in a relatively even fashion while activity in other stands either accelerated or declined. There is certainly no suggestion that Yudnapinna topfeed stands all behave alike.

Most Yudnapinna stands exhibited periods of activity not related to particular rainfalls despite the arid habitat, which offsets any idea that "likely effectiveness" of precipitations (Beard 1968) is necessarily a first issue in the performance of arid-zone plants.

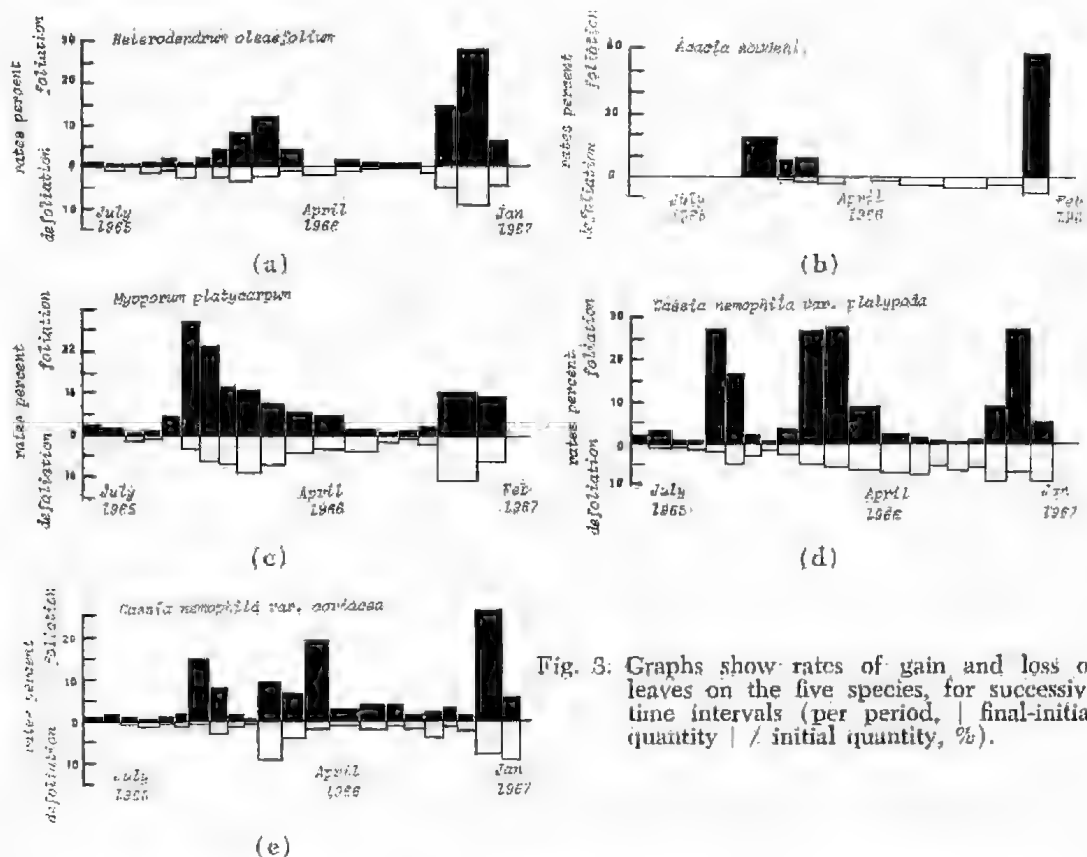


Fig. 3. Graphs show rates of gain and loss of leaves on the five species, for successive time intervals (per period, $\frac{\text{final-initial quantity}}{\text{initial quantity}}$, %).

Figures 2 and 3 show that topfeed canopy dynamics are revealed simply and clearly by tagging; a further step might be to relate sampled population to total stand canopy. This would be difficult; it is much more complex to document the course of events on every branch in the canopy, with respect to every leaf and bud it bears between its apex and most proximal leaf. The oldest leaves furthest from the shoot tip are more likely to fall than the tip leaves; taken into account, this would reduce percentage net gains to different, lower figures. Similarly, top canopy shoots and inner canopy shoots perform differently to each other and to

accessible shoots. Eventually, consideration of limb and whole plant input and death might be necessary. In practical terms, learning the added information might not justify the effort. Recourse to other techniques such as litter-trapping (Bray and Gorham 1964) might be explored first, since the question of what information is desirable must be balanced against the cost of obtaining it. No available method, however, appears superior to counting leaves on tagged shoots possibly combined with measurements of shoot length for following canopy dynamics, where the purpose is the interpretation of arid zone stands as range-land fodder components.

Ultimately, best advances may be made by considering stand production as of an assemblage of specified individuals studied separately. At present information is lacking whereby stand composition may usefully be specified; the typical Australian topfeed stand is an unknown entity regarding internal age and stage relationships, although data are accumulating.

Synchronization of foliation and defoliation in *Heterodendrum oleaefolium* prompts ideas that this synchronization holds for individual trees, that internal nutrient cycling could be involved, and that interesting physiological mechanisms will be found responsible. Further attention to this must await investigations of individuals, not of the stand as a whole.

ACKNOWLEDGEMENTS

The authors are grateful to the Rural Credits Development Fund of the Reserve Bank of Australia for financial support, to Mr. Dean of Yudnapinna Station for cooperation and help, and to numerous colleagues for assistance.

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OBITUARY:
FRANCIS JOHN MITCHELL, 1929-1970

Summary

OBITUARY

FRANCIS JOHN MITCHELL, 1929-1970

The senior Vice-President of the Society, John Mitchell, died at Belair on February 23rd, 1970, at the early age of 40 years. John was born at Adelaide on August 8th, 1929, and was educated at the Adelaide Technical High School. As a schoolboy he became deeply interested in reptiles and proficient at their identification. He spent his entire working life at the South Australian Museum, joining the staff as a junior cadet in 1946; he was appointed Assistant Curator of Reptiles in 1955, Curator in 1956 and Senior Curator of Vertebrates in 1965.

Mitchell's early research activities were in the field of reptile taxonomy, devoting particular attention to genera of the lizard families Agamidae and Scincidae. His first papers revealed a maturity of approach far in advance of his years, and he rapidly established himself as a highly competent taxonomist. In 1964 he commenced a study of the White Dragon Lizard *Amphibolurus maculosus* (Mitchell) inhabiting the salt crust of Lake Eyre, a step initiating a transfer of his interests to the field of animal behaviour. He visited Lake Eyre on numerous occasions, compiling considerable data on the lizard and its habitat. He designed new types of observation chambers at the Museum and there maintained observations on captive specimens for several years.

John Mitchell had diverse interests and actively promoted most of them. He was President of the Skin Divers' and Fishermen's Association in 1954, was the South Australian Open Champion from 1954 to 1957 and won awards at the Australian Championships in 1957. He founded the Underwater Research Group and was its President from 1958 to 1964. He acted as a judge for the South Australian Photographic Federation. He was a Foundation Member of the Australian Society of Herpetologists and for several years represented South Australia on its committee.

John served on the Council of the Royal Society of South Australia for twelve years as Treasurer (1959-67), Vice-President (1967-68, 1969-70) and President (1968-69).

For several years he suffered ill-health but he continued to place his voluntary duties to the scientific community before his personal research interests. The extent of this service restricted his research output but earned him the sincere respect of those who had the privilege to be associated with him.

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- 1950 Scincid Genera *Egernia* and *Tiliqua* (Lacertilia). Ibid 9 (3): pp. 275-308.
- 1951 The South Australian Reptile Fauna, Part I. Ophidia. Ibid 9 (4): pp. 545-557.
- 1953 A brief revision of the Four-fingered members of the genus *Leiopisma* (Lacertilia). Ibid 9 (1): pp. 75-90.
- 1955 Preliminary Account of the Reptilia and Amphibia collected by the National Geographical Society—Commonwealth Government—Smithsonian Institution Expedition to Arnhem Land (April to November, 1948). Ibid 9 (4): pp. 373-408.
- 1956 The problem of Polyphylogeny in Australian Reptile Classification. 16 pages, revised notes. Contribution to International Congress on Southern Hemisphere Vertebrate Taxonomy, Sao Paulo, Brazil.
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- 1958 Communal Egg Laying in the Lizard *Leiopisma gutchenoti* (Dunéril and Bihnan). Trans. R. Soc. S. Aust. 82: pp. 121-122.
- 1961 Results of the National Geographical Society—Commonwealth Government—Smithsonian Institution Expedition to Arnhem Land: Reptiles and Amphibians 4: pp. 309-342.
- 1965 The Affinities of *Tympanocryptis maculosa* Mitchell (Lacertilia—Agamidae). Rec. S. Aust. Mus. 15 (1): pp. 179-191.
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M. J. TYLER

**BALANCE SHEETS:
GENERAL ACCOUNT, ENDOWMENT AND
SCIENTIFIC RESEARCH FUND**

Summary

THE ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

GENERAL ACCOUNT

STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th June, 1970

RECEIPTS		PAYMENTS	
	\$		\$
<i>Opening Balance 1st July, 1969</i>		<i>Deduct Payments</i>	
Subscriptions	1,319.46	Publishing Costs	3,950.12
Government Grant	3,700.00	Cleaning Costs	178.90
Bank and Bond Interest	94.29	Postage	175.55
Reprints	681.40	Petty Cash	195.00
Sundry Income	79.81	Service Charges	48.20
		Stationery	47.81
		Insurance	102.44
		Sundries	165.37
		Visiting Lecturer	49.00
		Society Dinner (Deposit)	50.00
			4,962.39
		<i>Closing Balance 30th June, 1970</i>	\$1,921.79
	\$6,884.18		

LIBRARY ACCOUNT

STATEMENTS OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1970

RECEIPTS		PAYMENTS	
	\$		\$
<i>Opening Balance 1st July, 1969</i>		<i>Deduct Payments</i>	
Sale of Transactions	1,221.32	Wages	1,102.50
Bank Interest	61.40	Printing	650.00
Postage recovered	0.37	Binding	330.15
		Sundries	34.93
	1,283.09		2,117.58
	\$2,985.08	<i>Closing Balance 30th June, 1970</i>	\$867.50

THE ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

ENDOWMENT AND SCIENTIFIC RESEARCH FUND

STATEMENTS OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDED 30th JUNE, 1970

RECEIPTS		PAYMENTS	
	\$		\$
Opening Balance 1st July, 1969 ..	1,336.99	Purchase of Investments	
Add Receipts		20 Australian Consolidated Industries ..	105.51
Interest ..	1,384.50	600 Tubemakers of Australia ..	828.00
Bank Interest ..	41.01	200 Colonial Sugar Refineries ..	887.84
	1,425.51	10 Woolworth Ordinaries ..	12.80
			1,834.15
		Research Grants	
		F. Parker ..	200.00
		I. R. Goodwins ..	150.00
		T. G. Wood ..	150.00
		S. Barker ..	100.00
		S. Shepherd ..	100.00
			700.00
			2,534.15
	2,762.50	Closing Balance 30th June, 1970 ..	\$228.35

SCHEDULE OF INVESTMENTS AT 30th JUNE, 1970 (at cost)

	\$	\$
Fixed Deposit		
Leasworth Finance—8% ..	..	4,000.00
G.M.A.C.—7½% ..	..	2,000.00
F.C.A.—7½% ..	..	2,000.00
E.I.L.—8% ..	..	900.00
F.N.C.B. Waltons—7½% ..	..	2,000.00
		10,900.00
Equity Stock		
Woolworths—1,000 ..	..	1,302.80
Australian Consolidated Industries—700 ..	..	1,848.19
Adelaide Cement—1,000 ..	..	1,275.00
Colonial Sugar Refineries—600 ..	..	2,170.84
Herald Weekly Times—550 ..	..	1,814.76
Tooths—375 ..	..	1,330.00
Imperial Chemical Industries—500 ..	..	1,063.00
Leasworth Finance—875 ..	..	1,190.17
Softwood Holdings—Prefs—400 ..	..	800.00
Tubemakers of Australia—800 ..	..	828.00
		13,622.76
Inscribed Stock		
Cash at Bank ..	..	300.00
		228.35
		\$25,051.11
Note: Market Value of Equity Stock 30th June, 1970		\$15,032.00

AUDITORS' REPORT

We report that we have examined the Books and Accounts of the ROYAL SOCIETY OF SOUTH AUSTRALIA (INCORPORATED) for the year ended 30th June, 1970 and have obtained all the information and explanations we have required.

In our opinion, the attached Statements of Receipts and Payments for the General, Library and Endowment Fund are properly drawn up to record the cash transactions of the Society for the year ended 30th June, 1970 according to the best of our information and the explanations given to us and as shown by the Books of the Society submitted. We have also verified the Schedule of Investments at 30th June 1970.

Adelaide, South Australia,
10th September, 1970.

MILNE, STEVENS, SEARCY & CO.,
Chartered Accountants.

REPORT ON ACTIVITIES OF THE COUNCIL, 1969-70

Summary

REPORT ON ACTIVITIES OF THE COUNCIL, 1969-70

In the course of the past year twenty new members were elected and one person was re-admitted to membership. Four members died and fourteen resigned so that membership increased by three to the present record figure of 283.

In February 1970, the Society suffered a grave loss through the death of the immediate Past-President of the Society, Mr. F. J. Mitchell. The Council appointed Dr. K. R. Miles to fill the casual vacancy thus created.

Eight Ordinary Meetings of the Society were held and attendances ranged from twenty-one to seventy-eight. The average attendance of forty-eight was the highest in the Society's history.

The addresses presented at these meetings were as follows:

- September 1969: Mr. F. J. Mitchell (Presidential Address): "A biota without leaf or relief".
- October 1969: Dr. N. H. Ludbrook: "Ancient cultures of Mexico".
- November 1969: Mr. R. Hogg: "Heritable variations in populations of the Brush-tailed possum (*Trichosurus vulpecula*)".
- April 1970: The Society's Patron, His Excellency Major General Sir James Harrison: "The scientist under the microscope".
- May 1970: Prof. J. F. Lovering: "Geological history of the lunar surface".
- June 1970: Prof. A. A. Abbie: "Brachymesophalangy V. in Australian aborigines".
- August 1970: Dr. A. E. Newsome: "Mouse plagues: genesis and exodus".

In July 1970 a panel of speakers comprising Mr. Shepherd, Dr. Smyth, Dr. Womersley, Mr. Thomas and Mrs. Paton, presented contributions on the results of the expedition to Pearson Island.

Seventeen papers were read at the Ordinary Meetings. These comprised Botany (6), Zoology (6), Geomorphology (2), Geology (1), Limnology (1) and Palaeontology (1).

Eleven exhibits were also presented at the Ordinary Meetings. Most of these were provided as a result of approaches made by the Council to various scientific organisations.

The social function held in June 1970 took the form of an informal dinner held at The Colonial, Glen Osmond. Professor Neal addressed the meeting which was attended by thirty-five members and guests. His address was entitled: "Science in the Education of Human Beings".

Nine meetings of Council were held during the year.

In 1970 four awards were made from the Scientific Research and Endowment Fund to assist research being undertaken by members of the Society:

Mr. I. R. Goodwins of the Department of Genetics, University of Adelaide was granted \$150 to investigate the occurrence and distribution of the seeding tetraploid *Oxalis pes-caprae* (common soursob) in South Australia.

Dr. T. G. Wood of the C.S.I.R.O. Division of Soils received \$150 to undertake a taxonomic study of raphignathoid mites in the Berlese collection at Florence, Italy.

Dr. S. Barker of the Department of Zoology, University of Adelaide was granted \$100 to study nutritional anaemia in the Quokka *Setonix brachyurus*, a small wallaby population on Rottnest Island, Western Australia.

On behalf of a group of members, Mr. S. A. Shepherd was granted \$100, supplemented by \$150 from other society finances, to assist an expedition to St. Francis Island.

Volume 93 of the Transactions was published in December 1969. It contained seventeen papers and comprised 201 pages. The Griffin Press again acted as printers.

The Library continued to operate efficiently and profitably during the year, permitting the Council to embark upon a programme of reprinting early volumes of the Transactions. Volume 6 has been reprinted by the State Library and is now available for sale. One set of 80 volumes of the Transactions was sold.

A total of 2094 accessions were received; 8 new exchanges were negotiated; 366 volumes were borrowed from the Library, mostly on interlibrary loan, and 93 volumes were bound.

The Council wishes to express, on behalf of the Society, sincere thanks to Mrs. Dunlop and Mrs. Dougall for their service to the Society throughout the past year.

M. J. Tyler,
Secretary.

EXHIBITS

- I. M. THOMAS: Manganese nodules from the South Pacific Ocean.
- R. EDWARDS: Some preliminary results from excavations of small rock shelters near Beachport.
- G. MOUNT: A revised concept of conservative dentistry.
- I. M. THOMAS: *Peripatus* in the Adelaide Hills.
- B. TIMMS: AMDEL's role in the field of forensic science.
- Dr HJ. EICHLER: Some recent plant discoveries.
- J. HOGAN: The asthma weather/spore survey.
- Dr P. WILSON: Development of lungs in marsupials.

OFFICERS FOR 1969-70

Summary

ROYAL SOCIETY OF SOUTH AUSTRALIA

INCORPORATED

Patron:

HIS EXCELLENCY MAJOR-GENERAL SIR JAMES W. HARRISON,
K.C.M.G., C.B., C.B.E.

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S. A. SHEPHERD, B.A., LL.B.

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H. E. WOPFNER, Ph.D.

Auditors:

Messrs. MILNE, STEVENS, SEARCY & CO.

AWARD OF THE SIR JOSEPH VERCO MEDAL

Summary

AWARD OF THE SIR JOSEPH VERCO MEDAL

- 1929 PROF. WALTER HOWCHIN, F.G.S.
- 1930 JOHN MCC. BLACK, A.L.S.
- 1931 PROF. SIR DOUGLAS MAWSON, O.B.E., D.Sc., B.E., F.R.S.
- 1933 PROF. J. BURTON CLELAND, M.D.
- 1935 PROF. T. HARVEY JOHNSTON, M.A., D.Sc.
- 1938 PROF. J. A. PRESCOTT, D.Sc., F.A.C.I.
- 1943 HERBERT WOMERSLEY, A.I.S., F.R.E.S.
- 1944 PROF. J. G. WOOD, D.Sc., Ph.D.
- 1945 CECIL T. MADIGAN, M.A., B.E., D.Sc., F.C.S.
- 1946 HERBERT M. HALE, O.B.E.
- 1955 L. KEITH WARD, I.S.O., B.A., B.E., D.Sc.
- 1956 N. B. TINDALE, B.Sc.
- 1957 C. S. PIPER, D.Sc.
- 1959 C. G. STEPHENS, D.Sc.
- 1960 H. H. FINLAYSON
- 1961 R. L. SPECHT, Ph.D.
- 1962 H. C. ANDREWANTHA, M.Ag.Sc., D.Sc., F.A.A.
- 1963 N. H. LUDBROOK, M.A., Ph.D., D.I.C., F.G.S.
- 1965 R. V. SOUTHCOTT, D.Sc., M.D., B.S., D.T.M. & H.
- 1966 PROF. A. R. ALDERMAN, D.Sc., Ph.D., F.G.S.
- 1967 L. D. FRYOR, M.Sc., Dip.For.
- 1968 R. C. SPRIGG, M.Sc.
- 1969 H. B. S. WOMERSLEY, D.Sc.
- 1970 M. F. GLAESSNER, Ph.D. (Vienna), D.Sc. (Melb.), F.A.A.

For distinguished contributions over a wide range of palaeontological research, particularly in the evolution and morphology of foraminifera and crustaceans, and the Precambrian fossils of South Australia. Major publications include the "Principles of Micropalaeontology", which has remained a standard textbook in the field for 25 years, the section on Decapoda for the Treatise on Invertebrate Paleontology, and a monographic study of the Fossil Decapod Crustacea of New Zealand and the Evolution of the Order Decapoda.

Publications with his colleagues on the remarkable Precambrian fossils from Ediacara have been instrumental in attracting world-wide attention to this ancient fauna.

The author of over 120 publications, he has also made significant contributions to stratigraphic correlation and to the geology and palaeontology of Papua-New Guinea. He holds the position of Professor of Palaeontology in the Department of Geology of the University of Adelaide.

ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

NEW MEMBERS, 1969-70

- 1970 ALLEY, N. F., B.A., Geography Dept., University of Calgary, Calgary 44, Alberta, Canada.
- 1969 CHESSON, C. M., Dept. of Genetics, University of Adelaide, North Tce., Adelaide, S.A. 5000.
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